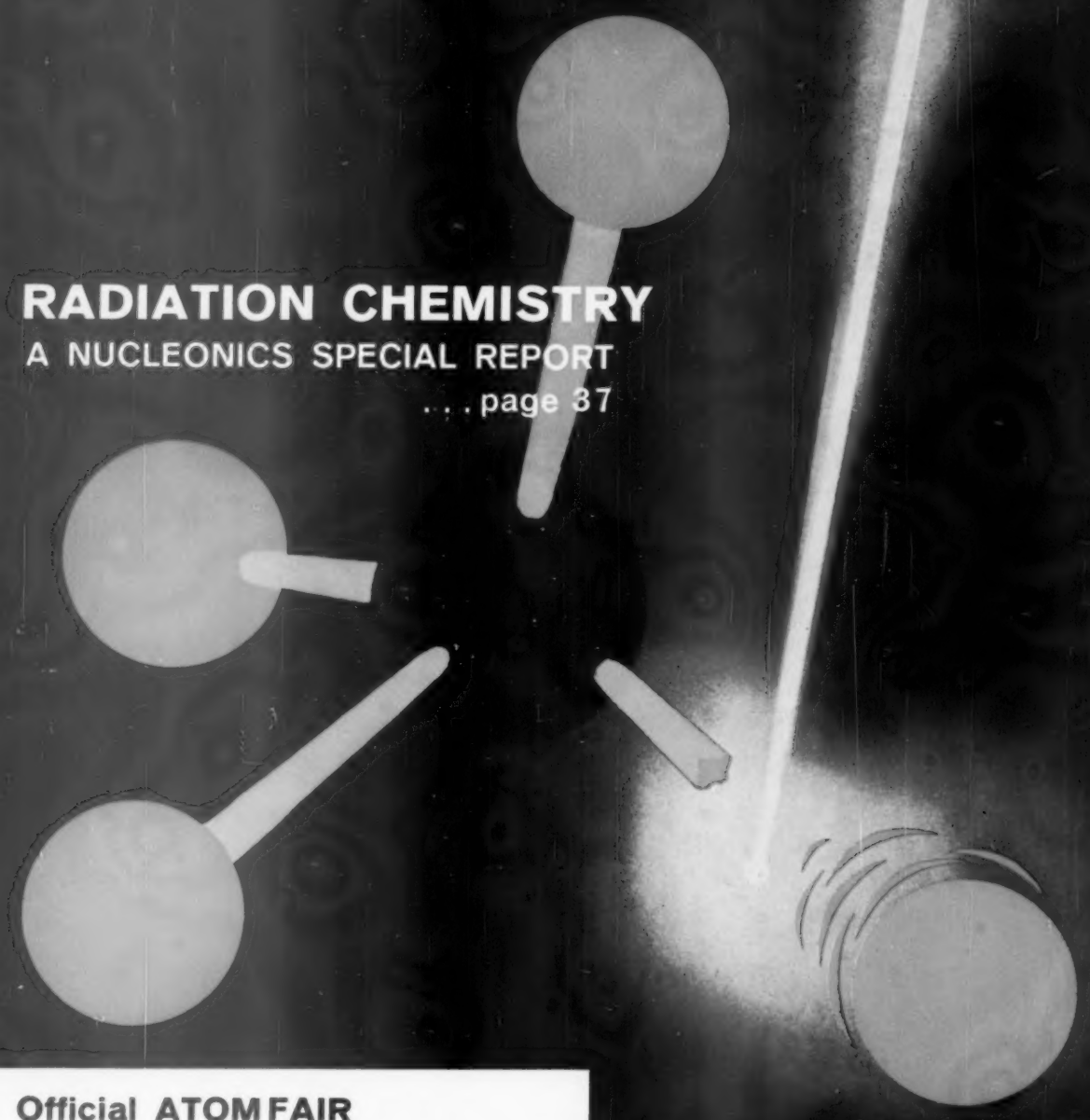
OCTOBER, 1961

NUCLEONICS

APPLIED RADIATION • ATOMIC POWER • NUCLEAR ENGINEERING



RADIATION CHEMISTRY

A NUCLEONICS SPECIAL REPORT

. . . page 87

Official ATOMFAIR Exhibitor Program . . . page 36A

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Above, technicians mark segment of casting for one of many hundreds of X-ray pictures employing a 24,000,000 volt Betatron at the Bonney Floyd Foundry. *Below*, X-ray picture is carefully inspected for flaws.

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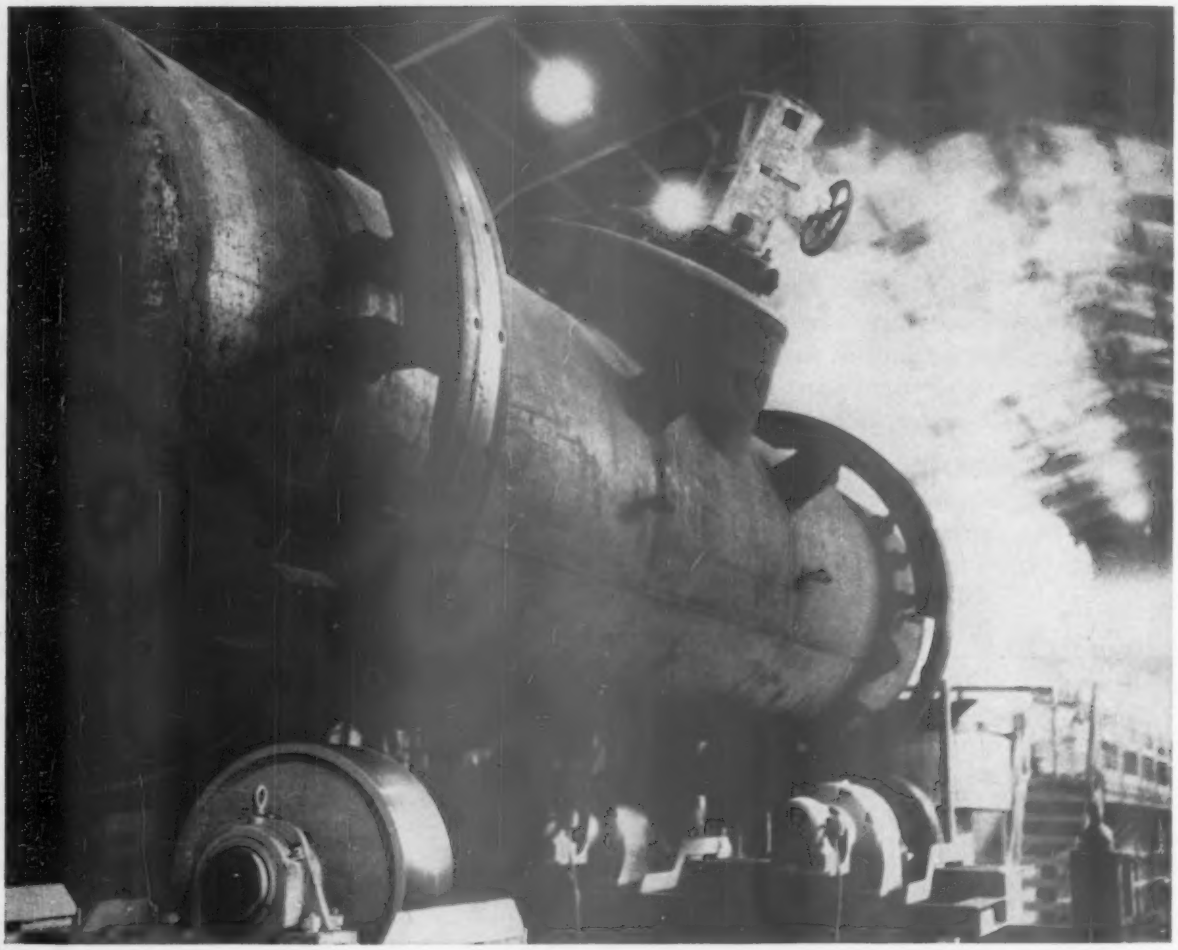

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...about NUCLEONICS

A Special Report

It's a long way from the grassy campus of a New Hampshire school to the pages of NUCLEONICS, especially if you have to hit Chicago, Los Angeles and Paris on the way, but that is the route our NUCLEONICS Special Report has traveled to reach the feature section in this month's issue. We'll tell you the story—not only because it's about this report but also because we feel it will show you how such reports are generally conceived, developed and born before we present them with the proud but apprehensive eyes of parents.

Our first intimate contact with the excitement of radiation chemistry came at the Gordon Research Conference devoted to that subject in July, 1960. Some 200 participants discussed rates and radicals in formal sessions, on swimming floats and golf courses, and over glasses and dining tables.

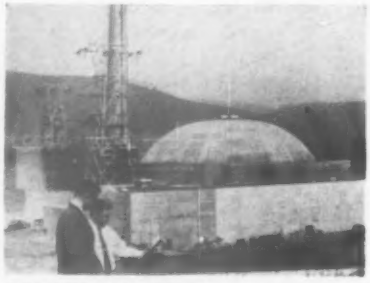
Edwin Hart, author of the article that starts on Page 45, became our consultant when we started work on the special report just a year ago. We are grateful to him for his comments on our ideas and those he added.

Letters to our authors went out last November, and when they accepted our invitations to write, we gave them deadlines for outlines, first drafts and final manuscripts. Meanwhile we commented on their outlines and manuscripts and asked them questions. Some of the authors wrote to one another to ensure that their efforts were well coordinated. Finally during the past two months we have written headlines, drawn our front cover, determined lengths and assigned page numbers. From that year of work and fun, therefore, we offer you our NUCLEONICS Special Report on Radiation Chemistry.

Buttoning Up Indian Point

Two of us (see figure) dropped in on the Consolidated Edison Indian Point plant a few days ago for a last look at parts that will soon become inaccessible as the plant prepares to go critical later this year. Con Ed remains enthusiastic. Costs are not too bad—about twice those of their conventional power by today's estimates. The homogeneous uranium-thorium-oxide fuel promises long-time stability and good burnup. Above all, Con Ed is proud to show that private power companies can make their contributions to advancing nuclear power technology with a minimum of public assistance.

The first Indian Point core is scheduled to produce 600 full-power-days in a plant designed to operate 40 years. Later cores may show improvement, but basic plant design will probably remain unchanged. Downtime is so expensive that improvements can be made better in future plants.



CON ED'S INDIAN POINT nears completion; Ellis and Dutton inspect

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COMING FEATURES

Annual Buyers' Guide (November)
Berkeley Fallout
Plastic Beta Counter
In-Core Instruments

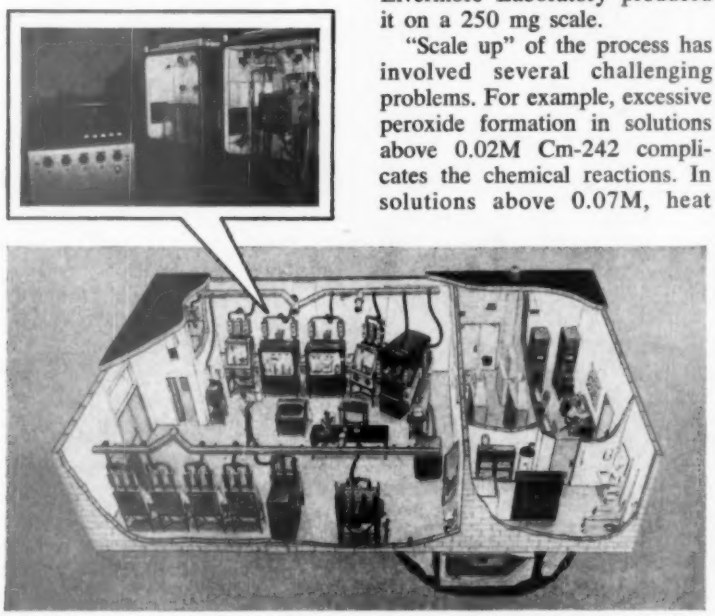
CURIUM-242 for Direct Conversion Generators

Development of direct conversion systems at The Martin Company includes the application of thermionic techniques as well as the thermoelectric techniques used in current SNAP programs. Thermionic generators seem particularly promising for space applications. This work has emphasized the need for an isotopic heat source of high power density which remains stable at the high operating temperatures (1500°K) required for thermionic diodes.

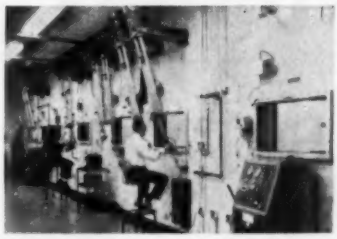
Curium-242 is an ideal power source because of its high power density, its potentially lower cost and the relative ease with which its alpha-particle emission can be shielded. While Polonium-210 and Curium-242 have equal power densities (100-120 watts per gram), Polonium compounds lack high temperature stability. Curium oxide (Cm_2O_3) melts in the neighborhood of 1800°K.

Recognizing the need for high temperature heat sources, Martin has undertaken, under contract with the U.S. Atomic Energy Commission, to "scale up" Curium-242 production on a multi-*gram* level. Discovered in 1944, Cm-242 had only been made in tracer amounts until 1960 when the University of California's Livermore Laboratory produced it on a 250 mg scale.

"Scale up" of the process has involved several challenging problems. For example, excessive peroxide formation in solutions above 0.02M Cm-242 complicates the chemical reactions. In solutions above 0.07M, heat evolution itself becomes limiting. This localized high energy release dictates special techniques for ion exchange, precipitation and handling of Curium compounds.



Martin-Nuclear Heavy Element Processing Facility, Baltimore, Maryland



Martin hot cell facilities, Quehanna, Pennsylvania

The production process, under direction of the Nuclear Chemistry Department at Martin's Nuclear Division, begins in the Heavy Element Processing Facility now in operation at Baltimore. This facility is capable of purifying 100 grams of Americium-241 at one time and encapsulating individual aluminum targets each containing 4 grams of AmO_2.

The Americium-241 targets will be irradiated at fluxes exceeding 10^{14} n/cm²/sec at the AEC National Reactor Testing Station in Idaho. After irradiation, each target will yield about 1.5 grams of Curium-242.

Remote chemical purification of Curium-242 by ion exchange techniques and conversion into high melting point compounds for use in direct conversion systems will be accomplished at the hot cell facilities operated by Martin at Quehanna, Pennsylvania.

Martin Heavy Element Processing Facility-Baltimore
AEC National Reactor Testing Station, Arco, Idaho
Martin Hot Cell Facilities, Quehanna, Penna.
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Purification & Target Preparation
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Curium-242 Separation, Purification-Conversion
Cm2O3 PELLETS

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NUCLEAR REACTIONS

Pumps, Valves, Heat Exchangers

DEAR SIR:

Your special report "Pumps, Valves and Heat Exchangers" (NU, July 1961, 53) is interesting and should perform a service to the nuclear industry. Specifically, the section on pumps is good and encompasses a great deal of objective reasoning. One item of considerable cost has been neglected on canned pumps, however, and this is concerned with lack of coastdown inertia of the canned pump. Manufacturers are now adding separate pump supply-house generators to keep these pumps turning at some considerable cost; this can be done very easily on the shaft-sealed pump by adding a flywheel. At the Yankee plant, which uses canned pumps, we do not have absolute and total coverage for flow inertia, and therefore, the cost reflects itself in accident analysis. This is hard to put a price tag on since it limits such things as core maximum capability.

In the section on valves by Mr. Gruenwald, we find some items with which we disagree. Our experience after ~6,000 hr of hot operation and 4,000 hr at full power is different from what he reports. We are becoming convinced that exotic specifications on valves for the high-pressure main-coolant system are unnecessary and that conventional stainless valves for high-pressure high-temperature conventional steam plants are quite acceptable. Our high-pressure valves are now nearly all modified (with leak-offs disconnected) to conventional practice of a deep stuffing box. Using Teflon packing, we have almost zero leakage. Our main coolant-system leakage is so low that we almost can't detect it—less than 50 gallons a day. The only relief valve that has leaked is an exotic solenoid-operated nuclear-specification valve. All other relief and safety valves have essentially zero leakage. Our recommendations to avoid valve troubles are (a) to choose a reputable experienced manufacturer; and (b) to have a good valve test in the shop primarily for backseat leakage and secondarily for across-seat leakage.

—GLENN A. REED
Plant Superintendent
Yankee Atomic Electric Co.
Rowe, Mass.

[*Editor's note: Upon seeing Mr. Reed's letter, Mr. Gruenwald commented that he fully concurs with Mr. Reed's recommendations to avoid valve troubles and that the trend is away from exotic valve specifications.*]

DEAR SIR:

Certainly the discussions in "Pumps for Water-Cooled Reactors" (NU, July 1961, 55) outlined the problems in the area of primary coolant pumps. Although the article was directed specifically to this area, a certain amount of generalization makes it necessary to present additional facts so that your readers will have a complete picture of canned motor pumps.

Your article states that canned motor pumps were developed originally for military propulsion reactors. This is

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not correct since canned motor pumps were commercially developed before the requirements for military reactors were established. These developments were not only completed on private funds, but the designs, arts and production techniques were commercially available and used for developing large primary coolant pumps.

The article also indicates that canned motor pumps are much more expensive than conventionally sealed standard pump units. This statement is only true when applied to manufacture of these large primary coolant-pump units for reactors. There are thousands of canned motor pump units sold in other areas in the nuclear field every year. These units present an entirely different picture on costs and are in most cases competitive with standard sealed units. In fact, commercially produced canned motor pumps for all industry are in many cases more than competitive with standard units where the quality is comparable.

The article also mentions that canned motor pumps need improvements and that they are limited to handling fluids above 200°F because of the motor winding insulation and the bearing construction. These statements also can only apply to certain of the large military reactors since canned pumps are currently used in industrial and nuclear applications where fluid temperatures exceed 750°F.

The statements on improvements fail to consider the fact that there has been a continuous development program for 14 years on commercial units. All the improvements suggested in your article and many others not mentioned are a standard part of every unit produced for nuclear and industrial applications by this company.

—D. P. Litzenberg
Vice-President
Fostoria Corp., Huntingdon Valley, Pa.

NPR Pump Efficiency is 85%

Dear Sir:

In the table on page 62 of your article "Pumps for Water-Cooled Power Reactors" (NU, July '61) the NPR main process-pump efficiency is erroneously placed at 56%. The expected NPR pump efficiency should be ~85%.

—William J. Love
Consulting Engineer NPR Project
General Electric Co., Richland, Wash.

[*Editor's note: With a turbine drive that is 66% efficient, the over-all efficiency of the combined motor-pump unit would be 56%.*]

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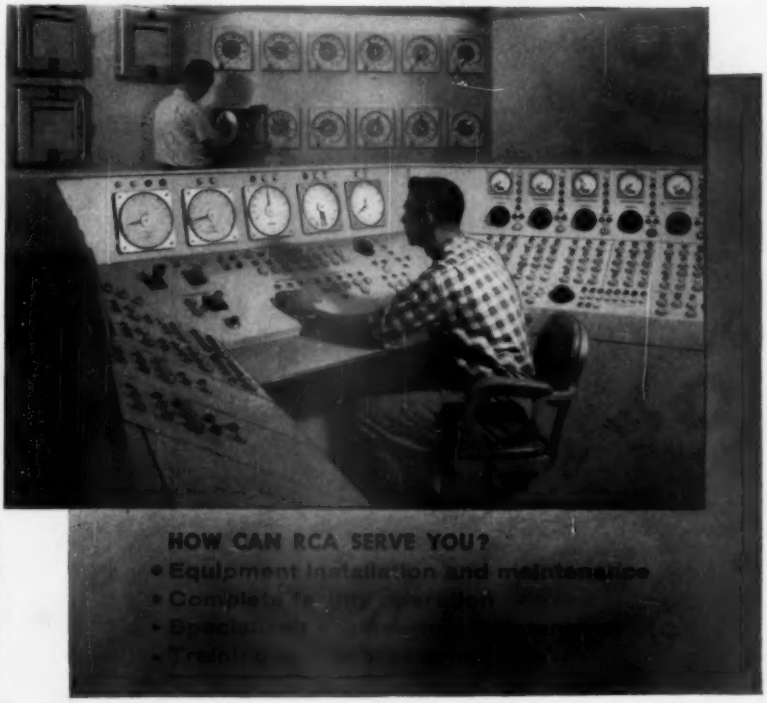
***Plum Brook*—RCA engineers supervised the installation and check-out of control room equipment for the nuclear reactor at the Plum Brook Reactor Facility of NASA, under sub-contract from Leeds and Northrup Company.**



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The reactor is currently used to train graduate students in practical nuclear engineering. Student engineers "learn by doing" under the watchful eye of qualified instructors and skilled technicians. Equally important, the reactor serves as a research facility for the Departments of Biology, Chemistry and Physics, and Schools of Engineering and Medicine.

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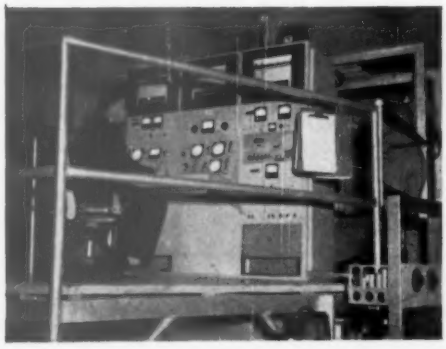
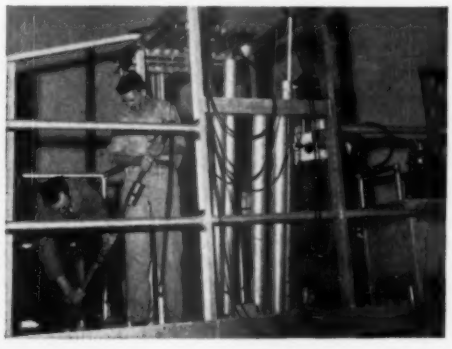


The Honeywell control console is located on a mobile bridge which spans the width of the pool. The bridge can be moved to position the core at any point along the length of the pool. Console instrumentation includes Honeywell ElectroniK 15 recorders (log count rate, linear power, log N), nuclear amplifiers, power set control unit, rod position indicators, and reactor scram annunciator.



The center of the control bridge functions as the nuclear work area. Supported from this point are the core, the control rod drive mechanisms, safety rod magnet assemblies, and neutron counters. Instructors and skilled technicians supervise and assist graduate students in setting up and performing reactor experiments. In this way, student engineers learn practical nuclear physics and reactor technology.

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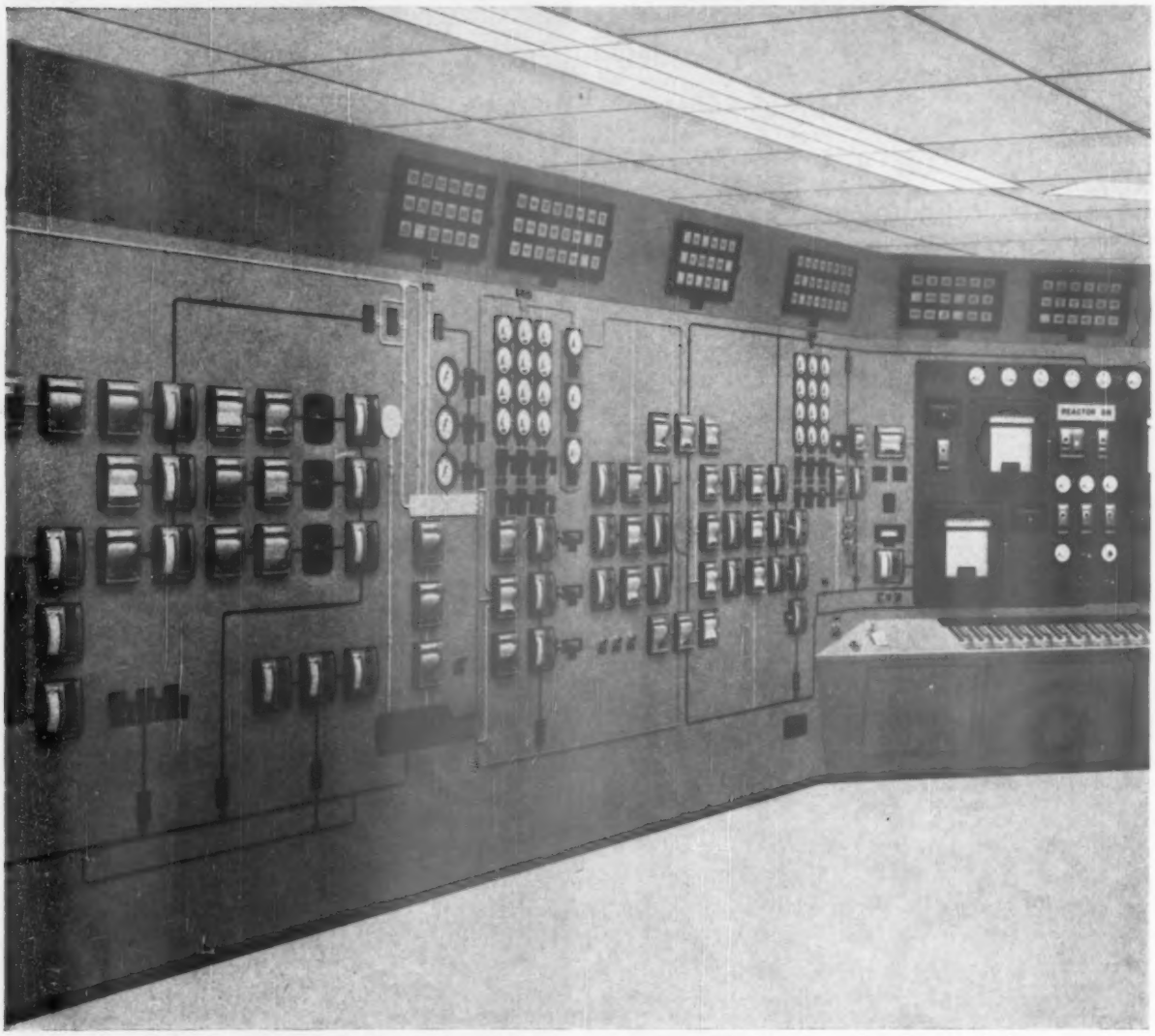
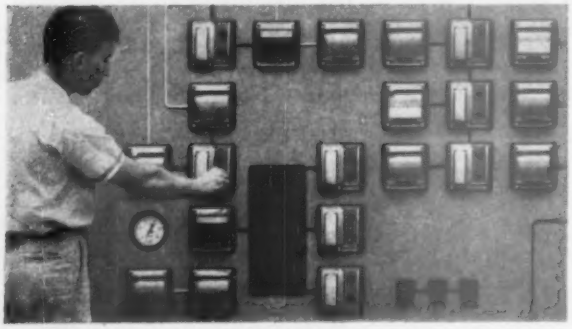
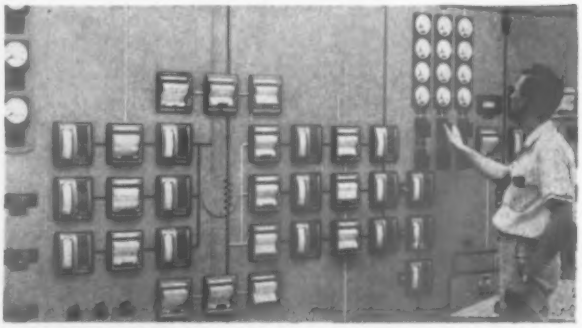


FOXBORO CONTROL PANEL at Sheldon Station, Hallam, Nebraska. Operated for the Atomic Energy Commission by the Consumer Public Power District. General Contractor: Peter Kiewit & Sons, Inc. Reactor design: Atomics International Division of North America Aviation. Architect-Engineer: Bechtel Corporation.



FOXBORO PNEUMATIC CONSOTROLS compute power demand and division of load for Sheldon Station. Consotrols also control plant's three feed water systems.



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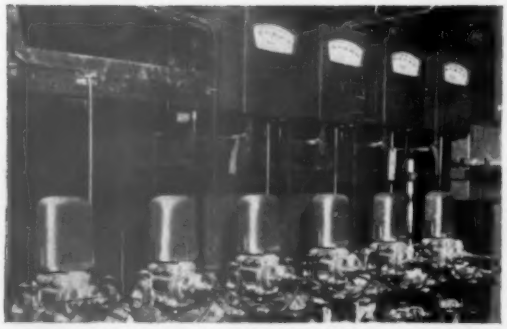

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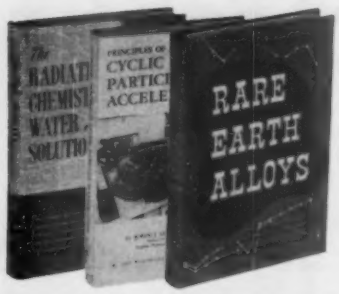

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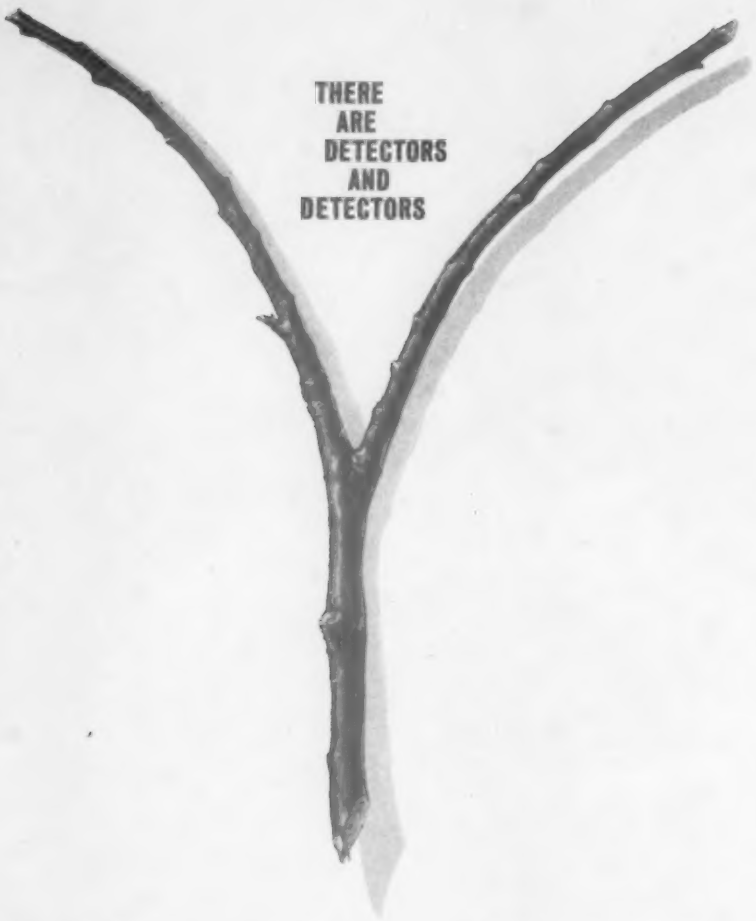

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NPR Fight, AIF Study Focus Attention on Reactor Outlook

What is the status of the power-reactor-marketing business in the U. S.? Where do the reactor vendors stand vis-a-vis each other? Who is trying to sell what and what is the disposition of the utility industry to buy? Are additional construction incentives needed at this stage of nuclear development and what is the outlook for adoption of such incentives in Washington?

These are questions which have been asked and answered frequently over the history of nuclear power but two unconnected activities in the nuclear field last month were giving them a new timeliness:

1. The controversy in Washington over power generation at the Hanford New Production Reactor, which, however uncertainly, has altered the attitude of the powerful Joint Committee on Atomic Energy toward the private-utility industry (*see Page 18 and NU, Sept '61, 21*); and

2. The work of the ad hoc Committee on National Policy on Peaceful Atomic Energy of the Atomic Industrial Forum (NU, June '61, 17), which was in the process of compiling the views of the Forum's members on whether and how something should be done to give nuclear power (and other nuclear programs) a new impetus.

Theoretically, the NPR fight and the work of the so-called Starr Committee* were unrelated. But the bitter struggle over NPR has raised real doubt that any reactor-incentive proposal suggested by the Starr Committee, when it completes its study later this year, would receive sympathetic attention at the JCAE. From a practical point of view, NPR may have rewound the reactor-marketing picture back to the point—this past spring—when everyone was asking what could be done in 1962 to invigorate power-reactor construction.

Forum Work Continues

Nevertheless, the Starr Committee was proceeding to gather industry views on nuclear power, space applications, maritime propulsion and industrial use of radiation—on the assumption that the situation might not be as bad as it looked.

Two questionnaires—a comprehensive one for 85 utility and vendor member firms of the Forum, a considerably shorter one for the 202 other U. S. members—were sent out on Aug. 7 for return during September. Proceeding concurrently were personal interviews, on a sampling basis, with utility and vendor executives; these were aimed at getting a realistic outlook on such basic factors as probable utility spending for nonnuclear fuels and vendor efforts to reduce costs of nuclear fuel.

Three members of the Committee have specific areas of inquiry—one each for radiation, space applications and maritime propulsion. Each was free to appoint his own subcommittee and send out his own questionnaire.

In its shorter questionnaire, the Committee asked four questions (paraphrased): 1. Should the national nuclear effort be increased or decreased in nine specified areas, including food and drug irradiation, medical applications and the use of nuclear explosives for peaceful purposes? 2. Which of 11 government policies or programs should be modified, including those involving reactors, fuels, isotopes development, atoms for peace and reactors for space propulsion and auxiliary power? 3. Which of 15 areas involve technical or economic deterrents to national goals, including raw materials, ownership of fissionable materials, reactor siting and safety, classification, and AEC patent and contract policies? and 4. Which specified sections of the 1954 Atomic Energy Act should be changed?

The longer questionnaire to utilities and reactor vendors asked these same questions and an additional 14 on reactor development.

With the NPR controversy raising doubts over the early adoption of reactor-construction incentives, NUCLEONICS conducted an informal survey last month on the reactor-marketing outlook sans incentives.

What is the mood of the nuclear power industry today? As always in this industry, the answer depends on whom you talk to. But basically, the mood is more sanguine today than it has been at any time in the last several years, even though the impact of the Hanford NPR fight is yet to be felt. The reasons are easy to see: the industry is already getting its first solid power reactor operating experience, and 467 Mwe additional capacity will go on the line in the next three months. One salutary effect that nuclear power is having on the utility industry is that the competition it is offering is forcing the price of conventional fuel down and providing a moving target for nuclear power.

The customers feel that progress is being made at the right rate, a rate commensurate with the state of nuclear technology and the comparative economics of nuclear power.

The vendors, operating for the most part on a deficit basis, are, of course, eager to see a more rapid growth of nuclear power plant capacity. This readily explains why, despite their general fundamental agreement in principle with the private utilities in the NPR fight, they tend in private to view the repercussions with more concern. And they also tend to be more in favor of government participation than the utilities.

On the customer side, plans for the next several years depend mainly on four things: 1. fuel-cost area that a utility is in; 2. extent of participation of a particular utility until now; 3. system size and load requirements, and 4. the political climate as it affects the utility industry.

Westinghouse signing contract for Givet reactor

Signing of a final contract for the 259-Mwe gross, 242 net SENA reactor—the Franco-Belgian project near Givet—was set for Sept. 25. The decision by SENA to go to contract signing removed all doubts about the Belgian share of financing of the plant that had hung over the project since the letter of intent of July 25, 1960. This is the biggest U. S. reactor yet exported.

* Chauncey Starr of Atomics International, chairman (see Page 36G).

Not surprisingly, the greatest immediate activity will be in the two highest-cost fuel areas of the country, California and the Northeast, where perhaps a million kw of nuclear capacity will be firmly committed within the next 12–18 months. Plans for part of this capacity—the 325-Mwe station that PG&E will erect at Bodega Bay—will be watched closely by the industry. Although PG&E's announcement that it will achieve 5.62 mills/kwh power cost and $181/kw capital cost have been questioned in parts of the industry, NUCLEONICS was impressed in an interview with N. R. Sutherland, president of PG&E, with that company's approach to nuclear power. A documentation of the facts on Bodega Bay will come out next month in PG&E's presentation to the California Public Utilities Commission.

Utilities in areas where nuclear power is on the edge of being competitive and where there is small hope for further reduction of conventional fuel costs are taking a hard look at when they should build their first nuclear station. At least one such told NUCLEONICS that its next station, to go on the line in 1965, will be conventional—but that the following plant, needed in 1967 or '68, could well be nuclear depending on how this utility sizes up nuclear technology in the next year when it must make its decision.

It is significant that two utilities already owning nuclear stations—New England Electric (Yankee Atomic's senior partner) and Consolidated Edison—are considered most likely to order nuclear stations within the next year. The New England System will need a station of 250–300-Mwe by 1966 and current thinking calls for the order of a nuclear plant from GE or Westinghouse about next summer.

With few, if any, exceptions, nuclear stations sold over the next few years are expected to be large (250 Mwe and up) and to be the type offering the most operating experience: water systems. This is true even though water reactors do not offer the modern steam conditions utilities want. But they do offer technology that can provide competitiveness in the next reactor generation or thereabouts, according to the fuel cost area of the country.

Other types of systems—gas, organic and sodium—will not "prove" themselves, via full-scale operating plants, for at least several years yet. But their vendor-sponsors are staking the future of their companies on the belief that the greater technical and economic potential of such systems will enable them to leapfrog today's water system suppliers.

It is this characterization of the technology that epitomizes the relative standing of the vendors. GE and Westinghouse, which have been concentrating on water systems, have made many more sales than the other companies. And they are also the ones that have been doing the most aggressive selling job and have the hottest prospects for near-term sales. The other vendors interested in the utility market could be divided roughly into two groups, with some overlapping: 1. those relying on advanced, high-temperature reactors still to be "proven" (General Atomic, Atomics International): and 2. "traditional" utility suppliers expecting to sell reactors and/or major components, when reactor demand begins to blossom, regardless of the Westinghouse and GE positions then (Babcock & Wilcox, Combustion Engineering, Allis-Chalmers).

By the fact of their present lead, GE and Westinghouse appear to be establishing marketing practices that are either unique to the nuclear field or that may very well affect the capabilities of other vendors to compete. These include: turnkey sales of entire nuclear-power stations; management of the entire fuel cycle; "battery type" warranties covering the first two fuel loadings; and full-core shifting to extend burn-up. Normal equipment guarantees are offered by both companies on nonnuclear components.

Each company is attempting, as well, to ensure its leadership via development work on advanced concepts: GE on nuclear superheat for water reactors, sodium-cooled fast reactors, and high-temperature gas reactors; and Westinghouse primarily on graphite-moderated, superheated water reactors (Westinghouse emphasizes it will build any type of reactor sought by a utility, including boiling water).

A rundown of the other vendors:

Allis-Chalmers: The company had no outstanding proposals as of last month but its engineering staff was "quite busy" on existing commitments such as Elk River, Pathfinder and the LaCrosse Boiling Water Reactor. The firm would like to see Pathfinder in operation before it attempts to sell a large, nuclear-superheat plant, but it would offer a fixed-priced boiling-water plant today. A–C also has a gas-reactor capability.

Babcock & Wilcox: B&W just recently embarked, with Stone & Webster, on an economic analysis of its spectral-shift concept (mixture of heavy- and light-water moderator), which the company hopes will help materially in its principal current goal: to get the spectral-shift concept into a central-station power plant of 250–500 Mwe. "For a large, central station we can be competitive or superior to straight pressurized water or boiling water." The company feels it does not have the financial resources to offer reactors on a turnkey basis. "Essentially, we would like to furnish steam plants—deliver a certain quantity of steam of a certain value at a time and place. In other words, sell nuclear steam generators as we now sell boilers."

Combustion Engineering: CE feels it lost four years (1955–59)—insofar as reactors for utilities are concerned—when it was involved almost exclusively in naval reactors. It has embarked on a program to expand its one-man reactor-marketing staff "considerably" in the next year, including the training of its present nonnuclear sales staff. "We don't have a central-station plant of our own right now," it was explained, but CE personnel have capability in water and gas-cooled technology. The company feels it will sell a plant in the 50–100-Mwe range before it attempts to market a large station. "We will have to rely to a certain extent on the tremendous prestige which CE has as a boiler supplier. . . . I am sure we'll be around selling reactors after some [of the others] have gone by the boards."

Atomics International: AI feels its organic concept (with organic or heavy-water moderation) will be competitive up to 200 Mwe in the U. S. and be particularly attractive overseas (natural uranium, all crude steel components). The firm predicts that its sodium-graphite, uranium-carbide concept will be competitive with Westinghouse and GE plants in two years—a period corresponding roughly to operational experience at Hallam and completion of a developmental program, which has been in negotiation with a utility group, on fuel fabrication techniques for U-carbide.

General Atomics: As the private company spending more of its own funds on controlled thermonuclear work than any other, GA has been concentrating on very advanced reactor concepts. A NUCLEONICS visit with GA shows its key personnel exuding optimism about the potential for its gas-cooled approach, based mainly on the HTGR design for Peach Bottom. But because this type needs to be proven, the company has not yet geared up to sell aggressively to the utility industry. GA, incidentally, has developed a dominant position in the research reactor field with its Triga reactor, and is now seeking to adapt the concept to what it calls an "absolutely safe" power package, in the 2 Mwe range.

NPR Conversion Killed; U. S. Nuclear Program Affected

By a larger margin than it had in early August, the House of Representatives last month defeated a proposed, one-generator compromise on the most controversial issue in the nuclear field since Dixon-Yates—production of power at the Hanford New Production Reactor. The defeat killed indefinitely the idea of adding large generating capacity to NPR and, in the process of ending this Democratic-sponsored proposal, raised the threat of both near- and long-term, adverse repercussions on the nuclear-power program in the U. S.

The stage had been set for the final House defeat of NPR power, which came on Sept. 13, when a Senate-House conference committee had decided on Aug. 31 to cutback a two-generator authorization (800 Mwe) to one generator (400 Mwe). In so doing, it was pointed out by the conference majority that 400 Mwe would be about Hanford's on site consumption, when the power became available in 1964, and therefore none of NPR's electricity would be marketed offsite.

Even before the one-generator idea had been formally considered by the conference committee, however, Republican opponents of NPR power (NU, Aug. '61, 21, 1) had made it clear that they did not consider one generator a compromise. Rep. James Van Zandt (R-Pa.) wrote a letter to each member of the House warning that acceptance of one generator "would not be a compromise but complete surrender to the will of the House."

Thus, on Aug. 31, the conference committee adopted the single approach over the opposition of Van Zandt and Sen. Bourke Hickenlooper (R-Iowa). In the 6–2 vote, the majority included: Reps. Chet Holifield (D-Calif.), chairman of the Joint Committee on Atomic Energy, and Melvin Price (D-Ill.), and Sens. Albert Gore (D-Tenn.), Henry Jackson (D-Wash.), John Pastore (D-R. I.) and Henry Dworshak (R-Idaho). The majority estimated one generator would cost $58-million, against $95-million for two, and would repay its cost in 9–11 years.

House Debate

Holifield, leading the effort to persuade the House to accept the one-generator "compromise," told the House that the 9–11-year estimate for self-amortization of the 400-Mwe generator was based on a power cost of only 1.7 mills/kwh, or less than the present cost of Hanford's power.

Holifield also emphasized that the conferees had had essentially three choices on NPR's conversion—in view of the Senate's having approved full power conversion after the House had approved none: 1. the Senate conferees could have stood fast on full conversion; 2. the House conferees could have stood fast against any power production; or 3. the conference could compromise on one generator —which it did.

As in the earlier debate, the NPR opposition in the House was led by Van Zandt and Reps. Craig Hosmer (R-Cal.) and Wm. Bates (R-Mass.). Their principal argument was this: that installation of one generator would be inevitably followed by installation of a second, thus putting AEC into the power business "on the installment plan." Bates insisted the project would actually cost $131-million: $58-million for the generator; $25-million already committed to permit conversion to power; $21-million in transmission facilities; and $27-million in operating expenses.

In the end, the House voted 251–155 against accepting the one-generator proposal, sending AEC's authorization bill (*see box*) back to a second conference. It was up to the conferees to decide which of the many plant-and-equipment items in the bill should be authorized this year. Meanwhile, Congress was proceeding with AEC's $2.3-billion operating budget for this fiscal year, after delaying action on this pending the outcome of the NPR controversy. Fiscal '62 funds for the plant-and-equipment items could not be appropriated until these projects had been authorized.

Effects of Fight

With the final defeat of NPR's conversion, the attention of the nuclear industry centered on the controversy's effects. There was no doubt that the defeat had put JCAE Chairman Holifield and other JCAE proponents of conversion in a seriously difficult bind. As Congressmen anxious to see the nuclear-power program go forward, they were reluctant to do anything to retard it; on the other hand, they had made it clear that they felt the private-utility industry was responsible for NPR's defeat. They felt that the one-generator approach threatened no harm to that industry.

On balance, then, some JCAE Democrats were expected to retaliate in some way. The short-range possibilities: strike from AEC's authorization bill all funds in direct support of reactors sponsored by private utilities; refuse to help Southern California Edison and its new partner, San Diego Gas & Electric Co., obtain the use of a 90-acre site at Camp Pendleton, Calif., for a 375-Mwe reactor ordered from Westinghouse Electric Corp. (NU, Aug. '61, 22). Longer range: adopt a hostile attitude toward any proposal tending to aid private utilities (*see Page 17*); create an atmosphere in which AEC would have less than an ideal relationship with the private-utility industry.

The Senate in mid-September passed AEC's fiscal-'62 authorization bill, despite fears that the defeated Democrats might try to block the construction program. The bill as passed included all previously-listed items except the Hanford generators. The $276.5-million authorization was to be signed by President Kennedy in late September.

Major Items in AEC Construction Bill

With the NPR power proposal defeated, it appeared possible last month that only a "bare-bones" version of AEC's authorization bill would be approved by Congress before it adjourns. Some congressional Democrats were threatening to block AEC's entire construction program until early next year—when Congress returns—but most observers felt that most of the construction program would be authorized this year. As approved by the conference committee, the bill authorized $333,440,000 in new or expanded plant and equipment ($58-million of this was for one NPR generator).

Other major items in the bill, as it went back to a Senate-House conference, were: $114-million Stanford linear accelerator; $19-million in third round aid for power reactors, including waiver of fuel use charges; $5-million for a fuel recycle pilot plant at Hanford; an increase in authorized cost of the Advanced Test Reactor, now under construction at Idaho, from $24-million to $40-million; $8-million for a beryllium-oxide-moderated, merchantship reactor experiment at Idaho; $6-million for organic test loops at the Organic-Moderated Reactor Experiment; $1.5-million for fission-product-recovery facilities at Hanford; $2.5-million for the Ultra High Temperature Reactor Experiment at Los Alamos; $3.2-million for a SNAP test facility at Atomics International; and authorization for AEC to proceed, under a cooperative arrangement with Dairyland Power Co-Op, Wis., with construction of the LaCrosse Boiling Water Reactor (builder: Allis-Chalmers).

Ramjet Future Uncertain But Acceleration Appears Probable

The nuclear-ramjet program (Project Pluto) appears headed for acceleration later this year, despite some signs that it could suffer the fate of the nuclear-airplane program, which was killed earlier this year by order of President Kennedy (NU, Aug. '61, 26). In an attempt to head off this possibility, the Joint Committee on Atomic Energy late in August conducted an unprecedented series of hearings (for so late in the Congressional session) on the ramjet and on progress in the nuclear-rocket and Systems for Nuclear Auxiliary Power programs (*see Page 28*).

In testimony curious and confusing in its contrasts—sometimes straightforward, sometimes cautious and evasive—witnesses from AEC, the Department of Defense (DOD) and the Air Force unfolded a story of Project Pluto over the last several months which is a study in bureaucratic complication.

In substance, the JCAE wanted an answer to this question: With the successful run of the first Pluto reactor experiment last May, is the program to be accelerated? For 2½ hours on Aug. 29, JCAE failed to get a clear answer to this question—primarily because there was no clear answer.

However, these highlights of Pluto's recent past and possible future emerged from the testimony of Harold Brown, DOD director of research and engineering; AEC Commissioner Robert Wilson; H. V. McMillan, assistant AF secretary for research and development; Col. Ola P. Thorne, assistant deputy chief of staff for the AF on atomic energy; and Theodore Merkle, director of Pluto-reactor development at Lawrence Radiation Laboratory, Livermore:

Recent past. In recent months, the joint AF–AEC management of Pluto under Brig. Gen. Irving L. Branch has been dissolved and the AF has downgraded the nuclear ramjet from Category 2 (fully funded) to Category 3 (funding if money is available). AEC is now conducting the reactor-development program on its own and the AF has transferred management of its vehicle- and engine-development responsibility to its AF Systems Command, under Lt. Gen. Bernard A. Schriever.

Current status. In the reactor-development program at AEC, the Commission was to begin, in late September or early October, a series of tests of Tory II-A prime—in the first attempt to take this reactor to full power of several hundred megawatts thermal (*see illustration on Page 21*). Meanwhile, the AF has completed its own review of the Pluto program and recommended to DOD in mid-August that it be permitted to go into engine-development and ground-test of a ramjet engine, beginning next July 1 (fiscal '63). In the process the program would automatically be restored to Category 2. The AF, subject to DOD budgetary approval, has asked $41-million for fiscal '63—against only $7-million this fiscal year.

Ramjet's future. AEC is committed to take the reactor-development effort through a prototype engine reactor—Tory II-C; tests of II-C would begin late next year and be completed in early calendar '63 (or late in fiscal '63), if the test program is carried out without major setbacks. In the meantime, both AEC and the AF are looking to the Defense dept. for advice this fall on the program's future. Research and Engineering Chief Harold Brown, who will be the key man in the DOD decision, has named a nine-man ad hoc committee to report to him by late September on feasibility of the nuclear ramjet.*

The decision he subsequently reaches will determine: 1. whether the AF will be given all or most of the $41-million it has requested to proceed with engine development; and 2. whether AEC will be asked later this year to proceed with an engine-reactor-development program beyond Tory II-C during fiscal '63.

Outlook Favorable

Thus, the stage is set for acceleration of Pluto at both AEC and the AF, beginning in fiscal '63, unless DOD blocks the acceleration this fall. Brown's position as of late August was essentially this: that, although he has long been a believer in the feasi-

* "Ad Hoc Group for Evaluation of Nuclear Ramjet": Chairman, Allen E. Pucket, Aerospace Corp.; Howland H. Bailey, Rand Corp.; Joseph G. Beerer, North American Aviation, Inc.; Arthur T. Biehl, MB Associates; William Bollay; Carl A. Covington, Defense Dept.; Alexander H. Flax, Cornell Aeronautical Lab.; Payne Harris, Los Alamos Scientific Lab.; Russell O'Neal, Bendix Corp. Air Force advisor to group: Col. Ola P. Thorne; AEC advisor to group: Allen J. Vander Weyden.

AF Thinking on Ramjet Outlined by Thorne

The Air Force decision to "follow on" development of the Tory II-C nuclear-ramjet reactor with engine development and ground test of the engine was described late in August by Col. Ola P. Thorne, assistant deputy chief of staff for atomic energy research and technology. Appearing before the Joint Committee on Atomic Energy (story this page), Thorne said the AF had asked Defense Department approval to budget $41-million for this "follow-on" work in fiscal '63. At this time next year the AF would have to decide whether to go on to flight-test, possibly in 1965. Thorne's testimony:

"The Air Force believes that nuclear ramjets may well have the performance capability required to give us the force flexibility desired in the post 1970 time period; however, we feel that one cannot as yet define a specific system requirement, since the weapon system program risk and probable cost cannot be sufficiently delineated at this time. These risks are as much concerned with airframe and nonnuclear subsystem development as they are with nuclear components, even though we have undertaken to identify and evaluate many of these specifics, including guidance systems and aerothermodynamic characteristics of a low altitude supersonic missile. This latter work has already produced vital information and feedback between the Pluto project people at the Lawerence Radiation Laboratory, Marquardt, and Vought Aeronautics, and is enabling us to define realistic system parameters and operating requirements.

"In addressing ourselves to the immediate question of the follow-on program to Tory II-C and the establishment of future program objectives, it is the opinion of the Air Force that a follow-on program for ground test of a nuclear ramjet engine would be a logical next major technical milestone. A ramjet engine designed to run on nuclear heat, using the Tory II-C configuration, could be built and tested in the chemical mode. Then the reactor could be integrated with the ramjet inlet and exhaust to provide for the ground testing of a nuclear ramjet engine simulating a specific flight regime. The simulated flight regime would cover boost to supersonic ram speed, reactor start and climb to high altitude on nuclear power, level-off at near sea level, stabilize and operate at supersonic speed.

"The Air Force considers this to be a valid approach to the problem, prior to committing the much greater funding required to develop a specific weapon system. Paralleling the ground testing of the nuclear ramjet engine, the Air Force would expect to conduct a substantial program of nonnuclear component and subsystem development, including airframe and application studies, designed to provide answers to the other high-risk questions. This work, coupled with the nuclear-engine ground test program, would provide us with the most effective base from which to later initiate development of a flight-test system, if desired."

bility of the Pluto reactor (most recently as director of Livermore until he took his DOD post in May), he must evaluate the feasibility of the ramjet as part of a weapons system which must compete with other weapons systems that might be able to do the same job better.

The most discussed application for a nuclear ramjet has been as a supersonic, low-altitude missile (SLAM), which would go in on a bomb target at three times the speed of sound and under radar screens. An unmanned airbreather, it would not require a fuel supply—thus operating for as long as the reactor held up at the proposed operating temperature of 3,000°F or more.

Test of Tory II-A1
May 14, 1961

	Planned	Achieved
Peak power (Mw)	40	50
Time at peak power (sec)	60	200
Air flow (lb/sec)	113.5	122.5
Inlet temp. (°F)	400	400
Fuel-element wall temp.(°F)	2,250	2,000

Under sharp JCAE questioning on his position, Brown made it clear that there were only so many AF dollars available for development of weapons systems and that this was his reason for refusing to commit himself on a decision until he had a chance to review the entire situation. Most observors, however, were predicting that the ad hoc committee would report favorably on the nuclear ramjet's feasibility and that Brown would authorize a go-ahead on engine development.

If so, there will be an industry scramble for the engine-development and reactor-development contracts similar to that which took place earlier this year on the nuclear-rocket engine. Marquardt Corp., which has been active in the Pluto program for several years, is virtually unrivaled as the leading candidate for engine development (nonnuclear). However, several reactor firms are interested in the nuclear portion of the engine, notable among them Aerojet-General Nucleonics and Westinghouse Corp. As for the entire ramjet system, Chance Vought Corp. has invested far more money and effort into a possible nuclear-ramjet missile than any other airframe manufacturer.

As of this fiscal year, AEC and the AF have committed $97.5-million to the Pluto program, most of it for reactor development. Under the AF proposal to go to engine development in fiscal '63, initial flight-test target would be fiscal '65 and estimated cost for reaching this goal is $400–500-million.

Martin Asks Early Expansion of Radioisotope Production To Forestall Shortages for Isotopic-Power Generation

The era of isotopic power formally "came of age" in late August when the Martin Co., major contractor to AEC in this technology, appealed to AEC and the Joint Committee on Atomic Energy for a large-scale, long-term program for production of generator-type isotopes to forestall a shortage. The Martin plea has clearly marked the crossover of radioisotopic-power technology from "Will these devices work?" to "Will there be enough to meet the demand?"

Testifying at JCAE hearings on Systems for Nuclear Auxiliary Power (SNAP), Jerome G. Morse, Martin's director of auxiliary-power systems, estimated there were some 20 possible space missions for isotopic generators and said the company was "deeply engaged in the study of several sea-based and undersea applications including sea-based weather stations, surface and subsurface navigation aids, passive and active detection systems, telephone repeaters and oceanographic research power systems. Remote land-based systems under study include weather-station networks, fallout measurement and seismic detection devices, fire-warning systems and navigation aids."

However, Morse said there were two particular problems affecting acceptance of isotopic generators by both military and nonmilitary potential users: 1. "misinformation or lack of complete information" among the users and potential users; and 2. "the lack of an established program to ensure reliable data on fuel costs and availability."

On the second—and more crucial—point Morse and Charles E. Crompton, director of Martin's Nuclear Chemistry Department, suggested expansion of AEC's isotope-separations capacity to produce several megacuries a year of Sr-90, Cs-137 and other waste-stream isotopes of interest for power generation. Martin and Air Reduction have, for some time, been proposing a joint industry-AEC program under which Martin-Air Reduction would build a separations plant at Hanford Works. However, the Martin witnesses indicated that construction of the facilities was more important to the company, at this point, than whether industry operates them:

"Whether a separation plant is to be operated by AEC or by private enterprise is really secondary at the moment," Crompton said. "Its scale and its approach are paramount in importance." A plant of several megacuries in capacity, it is felt, could both assure a large supply and substantially reduce the cost of separated isotopes.

AEC Position

AEC General Manager A. R. Luedecke testified that AEC had embarked on a three-phase expansion program at Hanford two years ago "which we hoped would provide assurance on the isotopes we needed as the requirements developed" and, at the same time, permit AEC to work out separations processes. In fiscal 1961, he said, Phase 1 was completed via modifications of Hanford's capability for taking specific cuts from waste-product streams; the Phase 2 schedule calls for construction of a prototype separations plant this fiscal year.

Phase 3, Luedecke said, calls for expansion of the prototype in fiscal '63 "if, in the meantime, we have not found a solution whereby industry could come in and participate." He indicated AEC would ask industry to submit proposals on separations participation between now and next spring, when AEC would probably arrive at a decision. The new AEC Division of Industrial Participation has been active, as have other areas of the AEC staff, in evaluating the question of AEC's going it alone on isotope separation or working out a partnership approach with some industrial firm or team. As it has on other occasions in the past when industry-vs-government activity has been a question, the cost of separation may be the deciding factor. Can industry do the job at a cost not too far out of line with the government's cost?

"We [will go] over with industry all the proposals involved and the costs, as we see them, and give them an opportunity [to participate]," Luedecke testified.

Essentially, Martin has asked AEC to take a long-term isotopic-fuels-supply position on both waste-stream isotopes (Sr^{90}, Cs^{137}, etc.) and artificially produced isotopes (Cm^{242}, Po^{208}). For waste-stream isotopes, Martin feels, annual separations capacity of at least 4–5 megacuries of Sr^{90} is essential (Cs^{137} would be an automatic byproduct of separating strontium). Martin had no specific recommendation on increasing production of reactor-produced isotopes, although Crompton pointed out that a few Surveyor generators—which will use Cm^{242} (*see Page 28*)—would consume a full year's production at the only facility now available for processing curium into fuel elements (Martin's Quehanna, Pa., hot-cell complex).

BEFORE AND AFTER CLEAN-UP: Photo at left shows SL-1 reactor top just after accident Jan. 3 (compare photos NU, Feb. '61, 21). Right, as it is now following clean-up and decontamination by General Electric. Bags contain lead shot for shielding.

SL-1 Radiation Down Sharply After Cleanup; Remove Vessel?

Disassembly of the SL-1 reactor vessel probably will begin in 2–4 months when, AEC officials estimate, radiation will have dropped to a safe level. By early last month, radiation readings had already dropped 90% since the accident Jan. 3 that took three lives. From 500–1,000 r/hr in the reactor room immediately after the accident, activity had decayed to maximums of less than 200 r/hr in April, 10–15 r/hr by early September.

Main question at present is whether General Electric, the SL-1 decontamination contractor, can fulfill its expectation of being able to remove the entire reactor vessel bodily and transport it to the former Aircraft Nuclear Propulsion hot shop, 25 miles north of SL-1 in the National Reactor Testing Station. GE has removed all loose equipment, tools and debris lying about the operating floor; cleaned and vacuumed the entire operating room floor (*see photos*) and the fan floor above it to remove radioactive dust, particles, pieces of shielding material, etc. Sheet steel and bags of lead shot were placed over the reactor top and its still-open ports. A hole is being cut in the reactor top large enough to permit an overhead crane to lift out the big pieces of equipment on the fan-room floor (air-cooled condensers, condenser fans, air-mixing chambers, etc.). Once this has been done, the entire building will be cut down to the operating floor to permit lifting out of the reactor vessel.

If this is successful, the vessel will be placed on a low-boy truck trailer, and into an already-existing frame (left over from ANP) on which interlocking lead bricks can be stacked to form a cask about the vessel during the trip to the hot shop. On the other hand, should the vessel have swelled so much as result of the nuclear excursion as to make its removal impossible, shielding and working facilities will have to be installed at the reactor site for the job of inspecting and removing the melted-down core within the vessel.

GE is using about 100 men who can be said to be working full time. This includes the "behind the scenes people": those building fixtures and jigs, modifying instrumentation, doing health physics, running the closed-circuit TV, driving trucks. About 12 professionals head the effort, including eight in one group forming a project team, and four who might be considered foremen. Most one-time tasks on one-shot penetrations of the reactor building are accomplished by radiologically-trained Army troops from Dugway and other bases—as was the case in January when the urgent objective was to bring out the bodies of the three victims.

No special equipment is being used: "We have no science-fiction devices," a GE leader said. At most, some cranes have been modified to fit the needs better. GE has been on the job since about late May or early June.

Project planners hope to be able to expose the melted-down core to view from all sides before taking any of it apart, possibly by trepanning the vessel remotely in the hot shop. However, "we won't know until we see it," they caution.

Theory Exploded

Meanwhile, new evidence on the accident has come to light that casts doubt on the prevailing theory that sudden motion of the central control rod was the likeliest cause of the accident (NU, March '61, 64).

The new evidence was discovery on the fan floor early last month of a broken piece of rack from a control rod assembly. It was tentatively identified as the upper portion of the central control rod assembly.

Said AEC, "Further investigation of the status of the central control rod at the time of the incident indicates that the control rod extension was 'frozen' at a point below the top of the reactor due to collapse of the control rod extension guide tube. At the time that the control rod extension froze, the central control rod had been withdrawn 3 in. but still extended through the reactor core. This seems to cast doubt on earlier theories that the accident could have been induced by rapid and extensive motion of the central control rod."

"This puts us back on Jan. 3 as to understanding what happened," an AEC official told NUCLEONICS. The central control rod movement theory now rejoins the other half-dozen possible explanations put forward in the interim report of the Curtis Nelson investigating board. Like the others, it must be rated as conceivable but not very likely.

France Making Progress on 5 Power Reactors—1,000 Mwe

1,000-plus Mwe of nuclear power-generating capacity in France, under construction or close to an actual construction start, is making good progress.

At Chinon, the Loire valley site where the state-owned public utility Electricité de France has three power reactors—EDF-1, -2 and -3—under way, EDF-1's steel pressure vessel is now welded and hydrostatic tests at 1½ times the 335 psi operating pressure have been completed. EDF, quite frankly buying nuclear know-how as well as kilowatts with its investment in Chinon, learned the hard way how to weld the 4.2-in. thick steel plates that make up the 33-ft diameter, 75-ft high vessel.

During the first attempt, a long crack opened up alongside a weld after the vessel was half assembled (NU, Dec. '59, 26; Aug. '60, 28). EDF had to dismantle it and start welding from the beginning, using a more elaborate technique.

EDF now expects the first of the Chinon reactors—all of which are carbon-dioxide-cooled, graphite-moderated, natural-uranium-fueled—to go critical in late summer of 1962. Apart from the reactor itself, the plant is practically completed. The 82-Mw turbine-generator set needs only steam to go on the line; it has already produced some kilowatt-hours using steam from an auxiliary boiler. The critical component in the gas-coolant circuit, the main blower, ran during full-speed tests without a murmur, EDF reports. Among other major items ready to go are the heat exchanger and the computer-controlled cladding-rupture detection system which, fed with inputs from a simulator, has been running satisfactory 24 hr/day since April.

EDF-2 and -3: Bigger and Bigger

EDF-2, with which EDF will step up to 250-Mwe (gross) output in its three-step approach to the 500-Mwe reactor size that now seems to its planners to be the optimum for competitive nuclear power in France, is now scheduled to go critical in summer 1963. With its painfully-acquired welding know-how and the thinner (3¾-in.) plates involved for the 60-ft spherical pressure vessel in EDF-2, the utility expects no welding problems; in fact the lower half of the sphere is already welded together. Other parts of the plant are well along. Of the four heat exchangers, each in a massive concrete tower at the four corners of the plant building, one is completed, two nearly so, the fourth well under way; all are to be finished by year-end. One of the two 125-Mwe generator sets is installed.

Last of the three Chinon reactors, now scheduled to go on the line in late 1965, EDF-3 should reach the 500-Mwe (gross) level. Although its nominal rating is 375 Mwe, like EDF-1 and -2 it is conservatively rated (nominal ratings for the first two are 60 and 170 Mwe net, respectively). Nevertheless, the two 250-Mw generator sets slated to be installed in EDF-3 are a tip-off of what the designers expect the reactor will be able to produce with the second and later fuel loadings. Foundations for EDF-3 have been poured.

For EDF-3, the utility chose a prestressed concrete pressure vessel instead of steel strictly on a cost comparison and not because of earlier welding problems. Rupture tests made on two one-sixth scale models indicate no trouble ahead. "The results were more than satisfactory," reports a ranking EDF engineer. "On one model the pressure pumps failed before the concrete did and we had to use more powerful ones to get fissures." EDF plans to run rupture tests on a third model, this time at high temperatures.

SENA and EL-4

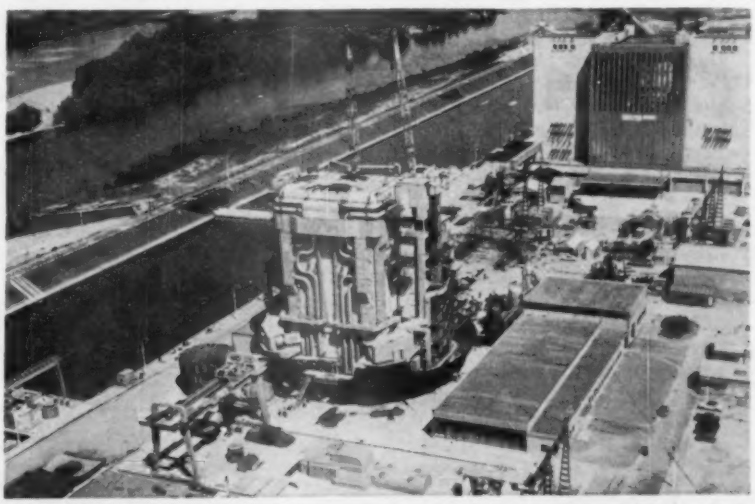
Besides its Chinon trio, EDF has a hand in two other reactor projects, both set for construction starts by Dec. 31. Equal partner with a Belgian utilities group in Société Nucléaire Franco-Belge des Ardennes (SENA), EDF will get into pressurized-water techniques with a 242-Mwe Westinghouse plant located underground at Chooz near Givet in the Ardennes forest, just inside France's border with Belgium.

Last major obstacle for this unit crumbled when Euratom recently decided (NU Wk, 13 July '61, 5) to grant $8-million aid to the project, being built under the U. S.–Euratom agreement. Although some details have yet to be settled before the letter of intent sent to the Westinghouse–Framatome–ACEC group is turned into a firm contract, SENA has issued invitations to bid on the civil engineering work. The reactor should be ready in late 1965 or early 1966.

Work should also start this year on the 80-Mwe gas-cooled, heavy-water-moderated reactor EL-4 that the Commissariat à l'Energie Atomique has scheduled for 1965 completion. Site is in the Monts d'Arrée area of Brittany at Brennilis near Morlaix. EDF is handling the heat exchangers and power generating equipment.

CEA wound up preliminary design for EL-4 late last year and expects to make the final design decisions this month. Major parameters, established after extensive research in UO_2 fuel and beryllium cladding technology, call for 18 tons natural U and 40 tons D_2O in the core, plus another 40 tons D_2O in the reflector. Gross thermal output is 225 Mwth. The fuel elements will be clusters of 19 pencils of 13-mm-diameter UO_2 pellets in smooth beryllium tubes. For the first loading, the fuel will be slightly-enriched U and the cladding stainless steel.

Preliminary design calls for zircaloy pressure tubes and a gas pressure of 870 psi with 500°F inlet, and 932°F outlet temperatures, with a maximum of 1,100°F at the cladding.



CHINON REACTORS EDF-1 (foreground) and -2 (right rear) near completion. Note EDF-1 sits in saucer-like base of what will be containment sphere.

REACTOR NEWS

ALCO RECOMMENDED FOR BYRD REACTOR

Alco Products Inc. has been recommended by AEC's selection board to build Antarctica's second reactor, the PL-3 at Byrd Station; AEC is now reviewing, and must approve, the board's choice. Ten firms had proposed on the job. The $7-million unit, to produce 1 Mwe plus 1.5-million Btu/hr steam, will be either pressurized or boiling water and will be installed under the ice, like PM-2A at Camp Century, Greenland—also an Alco reactor. First reactor in Antarctica is PM-3A for the Navy base on McMurdo Sound.

ESADA MAY ADD THIRD PROJECT

Empire State Atomic Development Associates was negotiating last month with a third reactor manufacturer on a joint development program in high-temperature reactor technology. Name of the manufacturer was being withheld pending outcome of the negotiations; however it's believed to be Atomics International, which was a strong third with its advanced sodium-graphite reactor in the original ESADA manufacturers' competition. Present ESADA contracts to explore high-temperature concepts that could be built in large (300–400-Mwe) sizes are with General Electric (boiling water superheat) and General Atomic (gas-cooled graphite-moderated).

SHIPPINGPORT: 2D REFUELING UNDERWAY

The Shippingport reactor was shut down for its second refueling Aug. 16 to get a new (third) set of 32 enriched seed elements to go with the original blanket elements. The work will be done on a faster schedule than the first refueling: 53 work days (three shifts, six days/week) are allotted for the job, as against the six months required the first time (Oct. 7, 1959—April 12, 1960). Seed 3 will be identical to Seed 2, and, like it, is expected to last 15 months from startup—scheduled for November. Shippingport produced 431.5-million kwh with Seed 2, as against 388.5-million kwh with Seed 1, for a total of 820-million kwh gross.

Meanwhile work is progressing slowly on the heat sink that will dump to atmosphere 50 Mwe equivalent of the 150 Mwe to be produced by Core 2 (which will succeed the 68-Mwe Seed-3-with-Blanket-1). The existing turbine has a maximum capacity of 100 Mwe (NU, April '60, 21). Cost of the modifications for Core 2, budgeted for $9-million, are reported to be presently estimated at more than twice that amount.

On another front, negotiations to renew the AEC–Duquesne Light Co. contract covering operation of Shippingport have been under way for a year, are not yet concluded. The contract dates from Dec. 18, 1957, expires Dec. 17, 1962. Negotiations are understood to be close to deadlock.

PEACH BOTTOM ASKS CONSTRUCTION PERMIT

Philadelphia Electric Co. has completed filing its application to get an AEC construction permit for its 40-Mwe High Temperature Gas-cooled Reactor at Peach Bottom, Pa. With the application went a 541-page preliminary hazards summary report intended to answer all questions about the reliability and safety of the General Atomic design posed last January by the Advisory Committee on Reactor Safeguards (NU, Feb. '61, 24), after Phila. Elec. submitted its original construction permit request on July 25, 1960. Final decision on issuance of the permit is expected in 3–5 months, an AEC official said. Phila. Elec. hopes to start construction at the site next spring, complete construction by March 1964, and be in operation by June 1964 at the earliest. Total cost estimate, $48,318,000, has remained about the same as when the project was first announced (NU, Dec. '58, 17).

A summary of General Atomic's answers to the points raised by ACRS: **1. Long-term integrity of graphite moderator:** A substantial amount of experimental data on damage criteria, dimensional changes, etc., has been tabulated, to provide evidence for belief in graphite integrity. **2. Feasibility of the fission-product retention and collection system:** Again, a large amount of experimental data has been tabulated. In addition, the peak (hot-spot) temperature in the core has been reduced from the original 3,300 to 3,029°F, a reduction said to be significant as fission-product release is relatively sensitive at these temperature ranges. One thing still to be established: integral tests of the entire system will be made using the in-pile loop in GETR (General Electric Testing Reactor). **3. Control rod reliability and safety:** In addition to the 36 normal control rods, 19 electrically-driven emergency rods have been added. They would not normally be used for control, but if the 36 normal rods fail, the 19 emergency rods would be driven in—by powerful drive motors that can force the rods in regardless of the condition of the core; GA calls these "pile-driver rods." Either group by itself has adequate shutdown margin. Still further: besides the normal and emergency rods, all bottom-mounted, a third tier of "last-ditch shutdown absorbers" would be hung above the 19 emergency-rod channels, possibly also above the 36 normal rod channels. These would be released by a fusible link arrangement in event of excessive temperature and would be gravity-dropped if the bottom-mounted rods were not already driven up into the core. **4. Lack of an emergency cooling system:** GA has provided one. It consists of a coil-jacket arrangement lining the reactor cavity outside the reactor vessel, to remove heat through the vessel walls in case of a loss-of-primary-coolant accident. **5. Relatively large assumed Doppler coefficient:** GA submitted results of critical tests at temperature to show that correlation with calculations has been very good. A project spokesman said the total cost consequences, of all the changes, "while not insignificant, in no way alter our optimism about the long-range outlook on plant costs."

MGCR TO BE BUILT IN ANP FACILITY

The Maritime Gas-Cooled Reactor prototype will be built in an ex-ANP facility instead of on the site of its own selected for it within the National Reactor Testing Station (NU, March '61, 31). The Shield Test Pool Facility in General Electric's Aircraft Nuclear Propulsion area at NRTS will be modified to house the 10-Mwth gas-cooled unit now called EBOR (Experimental Beryllium Oxide Reactor), formerly called BORE, first hardware stage in General Atomic's MGCR program. Kaiser Engineers has been awarded a $355,000 contract to design the necessary modifications in STPF. Kaiser is to complete its work early in 1962, with construction to start in spring 1962 and initial test operation scheduled in spring 1963. Use of STPF is expected to result in considerable savings on the project, for which an $8-million authorization is now before Congress.

NUCLEAR NAVY NOTES

The Navy's 22nd nuclear submarine, *Snook*, sailed on initial sea trials and became operational Aug. 27 . . . The cruiser *Long Beach* was commissioned Sept. 9 . . . Admiral Rickover went home from Bethesda Naval Hospital Sept. 9 after a heart attack July 25 (NU, Sept. '61, 28).

WORLD NEWS

Berkeley, Bradwell 1st Units Critical

Final reward of six years' work came for Britain's first two commercial nuclear power stations when the first reactors went critical at both the Bradwell and Berkeley twin-reactor stations, first planned in 1955 (NU, July '55, 14; Feb. '56, 15; Sept. '57, R10; Jan. '57, R5). Fuel loading began at Berkeley No. 1 Aug. 12 and at Bradwell No. 1 Aug. 14; Bradwell went critical Aug. 19, and Berkeley the night of the 19/20. Criticality was reached at Bradwell with 470 of 2,654 channels loaded, at Berkeley with 744 of 3,275. Both reactors are expected to reach full power by year's end (just one year behind original schedules), with the No. 2 reactors to go critical next spring.

2d U. S.–Euratom Bid Call Ready

The second joint U. S.–Euratom power reactor invitation was due to be issued late in September as this issue went to press. A final draft was under review by Euratom. Under the joint invitation, Euratom utilities would get a slightly better partnership aid plan for building reactors than has ever been offered U. S. industry: long-term nuclear fuel guarantees have never been underwritten by the U. S. government for American power utilities, but under the joint invitation with Euratom, the U. S. would provide long-term fuel guarantees, buy-back of up to 4,100 kg of plutonium, reprocessing services, and a 20-yr fuel supply. Euratom will offer research-development aid (up to a total of $32-million, divided between all bids) in the form of capital grants. Best prospects for submitting acceptable bids: the Franco-Belgian SENA project, building a 242-Mwe Westinghouse pressurized-water reactor; and Germany's KBWP, studying a 15- and a 150-Mwe Atomics International organic reactor with a view to selecting one for construction.

RWE Now Seen Serious on Big Reactor

There are "definite possibilities" that RWE, Germany's biggest electric utility, will order a 240- or 300-Mwe reactor next spring. If all went well, the unit—which would be the first full-scale power reactor in West Germany—could be completed by end-1965 or early 1966. RWE now expects to complete its evaluation of offers received late this fall (NU, July '61, 29). Indications are that RWE is no more just toying with the idea of building a full-sized power reactor, but is seriously inclined to go ahead with the project. RWE—which has built the 15-Mwe Kahl reactor—has been talking about a large reactor for four years (NU, Nov. '57, 19). The two offers RWE is studying are from a team of U.S. General Electric and Germany's AEC (the team that built Kahl), for a 302-Mwe boiling-water-cooled, graphite-moderated unit with internal steam separation and forced circulation; and from English Electric and Siemens, for a 237-Mwe gas-cooled Calder type. The German partner in each case would supply the majority share of the total order, in effect all except the reactor—but is keen to make at least parts of it, too. Power-generation costs of both proposed plants are said to be about the same. Main advantage of the U. S. offer is reportedly a considerably smaller capital cost; of the British, a smaller risk of technical difficulties since the Calder type is well proved. Planned location is in the Danube area between Ulm and Regensburg in central Bavaria. RWE has stated repeatedly that it would build a big reactor only when costs are competitive; freight charges for hauling coal from the Ruhr to Bavaria are such that nuclear generation costs are now calculated to be at the same level with hard-coal-produced power in that area. On financing: the Bonn government is understood to be ready to back eventual operating losses up to $25-million; the two teams bidding are each believed willing to shoulder up to another $7–8-million, and Euratom is counted on for some help.

Berlin Crisis Dims Reactor Hopes

The Berlin crisis has hurt the chances for the realization of the 150-Mwe reactor for which Berliner Elektrizitätswerk A.G. (BEWAG) had placed a preliminary study order with a team of Westinghouse–Siemens–Kaiser Engineers (NU, June '61, 25). Main objection to construction at this time, according to reports from on-the-scene sources, is fear that it might trigger a hostile move by East Germany, which has repeatedly said it would consider power-reactor construction in densely-populated Berlin a provocation. The underlying reason for East Germany's position, of course, is that a reactor would make part of West Berlin's power supply self-sufficient in case of a new blockade. Moreover, East German security regulations forbid reactor construction within two miles of residential areas, and the East Germans can be expected to protest on this ground.

Seven Offers on Tarapore

The Indian government opened seven offers to build a large-scale nuclear station on Aug. 31, deadline for bids on the country's planned 300-Mwe plant at Tarapore north of Bombay. In addition to two British and one French group proposing natural-uranium gas-cooled graphite reactors (NU, Sept. '61, 29), offers for other types came from General Electric, Westinghouse, Atomics International, and Canadian General Electric. Winner is to be selected in time to permit a construction start next March.

Plans for Big Reactor in Brazil

Brazil's government announced Aug. 25 it would proceed with construction of a 300-Mwe Calder-type reactor in the Paraíba valley (30–40 miles in from and parallel to the coast between Rio de Janeiro and São Paulo). This is the new location, in place of Mambucaba (NU, June '61, 22); exact site has not yet been disclosed. Bids were to be invited in 30 days, returnable in 180 days; ironically the announcement was made on the morning of the day that President Quadros later made the startling declaration he was resigning. It is not yet clear whether the consequent political crisis in Brazil will cause delay or dropping of the planned invitation. Also under study were two smaller reactors for the semi-arid, power-hungry northeastern region: a 50-Mwe station for the São Luis–Teresina area of Maranhão state (between Belem and Recife), and a 100-Mwe unit for another locality not specified. Prior to Quadros' resignation, bids had been expected to be asked on these by year's end.

B&W Gets JRR-2 Core Order

Babcock & Wilcox will fabricate a new, 90%-enriched core for the controversial JRR-2, the Japan Atomic Energy Research Institute's CP-5-type research reactor. The contract is for $100,000 and covers 30 elements—the core plus spares. JAERI officials hope the new fuel will permit JRR-2 to reach its design power level of 10 Mwth; with its first core JRR-2 has been able to operate only at 1 Mwth (NU Wk, 10 Nov.'60, 2; 29 June '61, 5).

NEWS IN BRIEF

AEC to Cover Contractor Bid, Bonus Costs

AEC decided in August to reimburse its contractors for costs incurred in preparing bids and proposals whether or not they are successful—provided the contract work bid on is applicable to the AEC program. In defining eligibility the Commission said that if both an AEC contractor and a firm not under contract to AEC bid unsuccessfully on a contract (during the annual accounting period in which the cost is incurred) only the AEC contractor will be reimbursed. Under terms of an amendment to AEC's cost principles, the commission will reimburse bidders already having AEC contracts for a sum up to 1% of direct labor and direct material costs of outstanding contract work. For example if an AEC contractor already has a $1-million research contract in which material and labor costs total $500,000, then AEC will provide up to $5,000 for bid preparation on another AEC contract. The exact amount will be determined on the basis of standards now being formulated by AEC's Division of Contracts and Office of Controller.

Incentive compensation. In another significant change, AEC announced that incentive compensation paid contractor employees will be considered an allowable cost item provided it is "reasonable" for services rendered and does not exceed costs allowed by the Internal Revenue Service for tax purposes. Incentive compensation will be paid contractors, subject to these conditions: 1. that the contractor previously provided an incentive-bonus plan, 2. that the compensation generally must conform to that paid by similar-size companies in the same industry. This new compensation policy parallels Defense Department practice.

The new principles generally reflect suggestions submitted to AEC earlier this year by the Atomic Industrial Forum.

Regulatory Authority Approved for Kentucky . . .

AEC approved for public comment last month a proposed agreement for transfer to Kentucky of its regulatory controls over radionuclides, source materials uranium and thorium and small quantities of special nuclear materials: U-233, U-235 and plutonium. The authority approved for transfer includes responsibility for rule-making, licensing, inspection and enforcement in use of these materials. It also includes authority to transport and dispose low-level radioactive wastes.

This was the first such agreement executed by the commission under provisions of a September, 1959, amendment to the Atomic Energy Act that permits transfer under certain conditions, namely a safe state program and its compatibility with the commission's program. Kentucky had completed submission of its proposal two months ago (NU, Sept. '61, 30). The agreement is scheduled to become effective Dec. 1.

. . . But Illinois Governor Vetoes Transfer Bills

While Kentucky sought regulatory authority another state, Illinois, decided against seeking it, when Governor Otto Kerner vetoed two State Senate bills that would have authorized transfer. If they had been signed Illinois would have been authorized to negotiate with AEC to assume regulatory authority. Gov. Kerner cited high cost of inspection activities necessary to provide the needed safeguards as prime reason for his action. To lower the cost he called for a "cooperative venture" under which the U. S. Public Health Service would share responsibility by acting in conjunction with state departments of health.

AEC Attempting to Define Nuclear Industry

Division of the nuclear industry into eight major categories—with appropriate subcategories—is being contemplated by AEC's Division of Industrial Participation as the first step in its attempt to encourage commercial activity in the nuclear field. Purpose of the proposed division is to identify the capabilities of companies to perform work required at AEC-owned installations. This is in line with AEC's attempt to make it easier for industry to participate in Commission programs.

Major categories, as currently proposed, are: raw materials, materials processing and fabrication, components, by-product applications, waste handling, reprocessing and recovery of materials, reactor applications and services.

If a successful breakdown-definition can be obtained, it could be very useful in developing two sought-after objectives: 1. a reporting system that might be used on a case-by-case basis to identify those companies able to perform specific tasks; and 2. an annual statistics-gathering program reflecting the state of the industry. Suggestions on this proposed program are being solicited from both associations and individual firms.

Fuel Transfers Featured in AEC's '61 Omnibus Bill

AEC's 1961 Omnibus Bill, which was signed last month by President Kennedy, provides for transfer of 500 gm of U-233 and 3 kg of plutonium (in Pu-Be neutron sources) to the International Atomic Energy Agency, transfer of 8 kg of plutonium and 30 kg of U-233 to Euratom and a provision formally abolishing AEC indemnification of licensees for "on site" property damage from nuclear incidents.

Reactor hearings. Meanwhile, the AEC-JCAE compromise to limit mandatory reactor hearings to a single hearing (NU, Sept. '61, 22)—which had been considered for possible introduction at this session of Congress as an amendment to the 1954 Atomic Energy Act—has been shelved until next session.

AEC Declassifies Nuclear-Aircraft Reactor Information

Nuclear-aircraft documents on both direct-cycle and indirect-cycle reactor approaches, estimated to number in the thousands, were declassified by AEC during a recently-completed review. The review, conducted by special teams, followed President Kennedy's decision to drop the two-approach program (NU, Aug. '61, 26). As a result all direct-cycle technology, except an "insignificant" amount on lightweight shielding, has been declassified. In addition a high percentage of indirect-cycle technology has also been declassified. This amount was proportionately less than information on direct-cycle technology, however, because of greater military interest in the high-temperature-systems technology developed in the indirect-cycle program.

Because so many previously classified documents are involved, it will be some time before the commission can supply nuclear-aircraft reactor information on request.

The availability of technological information on other aspects of the program (engine, airframe, etc.) will depend on Defense Department's willingness to declassify it.

SNAP classifications. Meanwhile, AEC has completed new classification guides for both reactor and radionuclide power sources in the SNAP program (Systems for Nuclear Auxiliary Power). AEC had decided to tighten up on SNAP technology in the space and military areas earlier this year (NU, July '61, 30).

RADIATION NEWS

Nuclide-Powered Weather Station Operational

The world's first radionuclide-powered weather station became operational in late August—somewhat in advance of earlier AEC and Martin Co. expectations (NU, Aug. '61, 25). High-pitched "beeps" picked up by short wave receiver at Resolute Bay, northern Canada, have marked the beginning of operation for AEC and U. S. Weather Bureau's automatic, unmanned station at Sherwood Head, on Axle Heiberg Island, north of the Arctic Circle. The station is expected automatically to transmit data on temperature, wind and barometric pressure for the next two years without need for refueling—an important factor in view of the station's inaccessibility. (Weather Bureau and Martin Co. technicians probably will be unable to reach the remote site again until mid-1962.)

The station, designed by Martin's Nuclear Division, under contract to AEC's Isotope Development Division, is powered by a 5-watt, 17,500-curie, strontium-90 generator (Sr^{90} in strontium titanate) and sealed in a corrosion-resistant metal capsule near the bottom of the underground power and instrumentation chamber. Heat from radioactive decay of Sr^{90} is converted into a continuous stream of electricity by 60 sets of thermocouples.

Nuclear Fuel Cell Being Fabricated for the Navy

A 5-watt nuclear fuel–cell prototype, is under fabrication for the Navy by National Carbon Co., division of Union Carbide Corp. It is being fabricated at Parma, Ohio, under terms of a $90,000 contract let by the Bureau of Ships' Advanced Concepts Division. In the concept, demonstrated as feasible, mixed fission products or a gamma source such as Co^{60} are used to break down ferrous sulphate and sulfuric acid to yield ferric sulphate and hydrogen ions which are converted electrochemically to ferrous sulphate and sulfuric acid. The process is regenerative. Expected efficiency of the cell is 3–4% of the radiation energy absorbed. (Theoretical efficiency: 6%.)

A Navy official estimated that the cell would operate for 30 years at a cost one tenth that of SNAP-3 ($1,000/watt–year vs. $10,000/watt–year), first radioisotopic generator prototype, and would be operated initially with simulated fission products, then with calcined fission products when available from AEC's plant in Idaho. National Carbon, however, would like to use Co^{60} initially.

Tracerlab Gets AEC Disposal License, Contract

AEC issued a waste disposal license to Tracerlab last month. The license, first step in the company's entrance into the waste-disposal business, permits the Massachusetts firm to receive and store low-level radioactive wastes and to transfer these wastes for land burial to Oak Ridge National Laboratory and the National Reactor Testing Station in Idaho. Under license terms, Tracerlab can possess a maximum of 100 curies of radioactive wastes that have atomic numbers between 3 and 83; 500 curies of tritium wastes; and 250 gm of special nuclear wastes (U-233, U-235 and plutonium) at one time. The wastes will be prepackaged in steel drums by customers, then shipped for storage in an underground storage room at the company's Waltham radioisotope laboratories. Meanwhile, Tracerlab received a $90,000 subcontract from Kaiser Engineers in late August to design and manufacture a 100-channel area radiation-monitoring system for the New Production Reactor at AEC's Hanford Works in Richland, Washington. The system is expected to monitor ambient gamma radiation levels at 100 points in the facility and to read out the levels on a central station panel that will be located in the reactor control room. Central station indicators equipped with alarms will signal the operator when the radiation level has exceeded predetermined settings. System components will include remote radiation transducers, remote readout and alarm light modules, power supplies, strip-chart recorders and a special patch panel for recorder output programming.

Stockholders Meet. Stockholders of Tracerlab and Laboratory for Electronics were expected to approve the merger of their companies at special stockholder meetings held Sept. 19 by the respective groups (NU, Aug. '61, 31).

RDI Enters Joint Venture on Irradiated Tubing

Radiation Dynamics, Inc., and Suflex Corp., Long Island insulation manufacturer, have entered into a joint agreement for production and marketing of irradiated, heat-shrinkable tubing for manufacturers of electronic components. Suflex will market the RDI-produced material, when RDI completes development of the new material.

In another development, RDI was awarded a new contract from Hospital Supply and Development Corp. to sterilize one million packages of disposable catheterization sets for the Pittsburgh firm during the next 12 months. After the packages have been sealed in airtight polyethylene bags in Pittsburgh, they are being shipped to RDI's irradiation service center in Westbury, N. Y., where they are then hung from an overhead conveyor and passed through a sterilizing beam of high-speed electrons emitted by RDI's particle accelerator, the Dynamitron. (Earlier contract: NU, Jan. '61, 28.)

Japanese Consider Radiochemistry, Drug Facilities

Two developments in Japan in late August have indicated the increasing importance of radiation applications in the country's industrial growth. They are: 1. proposed construction by the Japan Atomic Energy Research Institute of a $10-million radiation-chemical center; and 2. scheduled building early next year of a radiopharmaceutical plant as a joint venture with Abbott Laboratories and Dai Nippon Seiyaka, distributor of Abbott's pharmaceuticals, as participants.

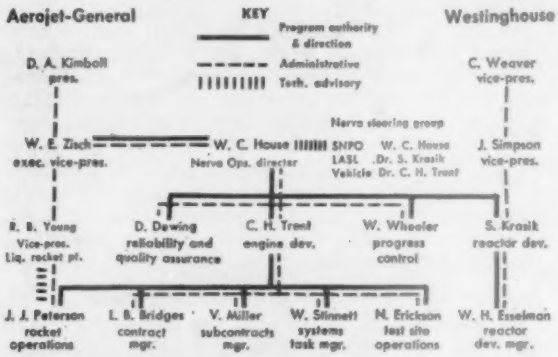
Radiochemistry. Japan's Atomic Energy Commission is soon to decide on authorization for a radiation-chemical center. (A favorable decision was expected in late September.) If the decision is favorable, JAEC is expected to ask the Diet to allocate $4.6-million of its fiscal '62 budget for the first year of a suggested five-year construction program that would begin next April. The proposed center would include: a 300,000-curie Co^{60} source, three high-energy (2-Mev) and one or more high power (12-kw) accelerators, chemical reaction vessels, spectrometers and other instrumentation. Projects assigned to the center would be selected and recommended to JAERI by the radiation-chemistry division of the Japan Atomic Industrial Forum.

Radiopharmacy. Unless the Japanese government objects, Japan's first radiopharmaceutical plant will be built in Matsudo, a Tokyo suburb, beginning in early '63. The joint venture, known as Dainabot Radioisotope Laboratories, Ltd., would be capitalized on a 50–50 basis with each participant providing $75,000. It would be a small plant that would produce both diagnostic and therapeutic radiopharmaceuticals—radioiodine, cobalt, etc., and would depend on Japanese facilities for its isotopes. Two Japanese technicians from Dai Nippon are training at Abbott's radiopharmaceutical labs at Oak Ridge, Tenn.

NUCLEONICS IN SPACE

Finger: Next Year Most Crucial on Nuclear Rocket

Nuclear-Rocket Manager Harold B. Finger told the Joint Committee on Atomic Energy in late August that the next year would be the most crucial in the history of nuclear-rocket development. Finger, AEC Chairman Glenn Seaborg and NASA Administrator James Webb had been invited to give JCAE a progress and outlook report on the nuclear-rocket program—in an unusual end-of-session review of the rocket, nuclear ramjet and SNAP programs. Finger said he felt that AEC should demonstrate the feasibility of nuclear-rocket reactors "within the next 12 months." Finger said that the Kiwi-B series of liquid-hydrogen reactor tests, to begin this fall with a final gaseous-hydrogen experiment, "is the most important in the Rover program." In effect, Finger was confirming what officials of Los Alamos Scientific Laboratory (LASL) had said earlier this year—it is hoped that by mid-1962 AEC will have a reactor around which an engine can be developed (NU, May '61, 22). Finger also described the organizational assignments made by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Aerojet General Corp. (engine contractor) and Westinghouse Electric Corp. (nuclear contractor) to carry out development of the nuclear-rocket engine (*see illustration*). Other nuclear-rocket news:

Fuel elements. A program of procurement of fuel elements for the engine-development effort has been under evaluation for several weeks by Finger's AEC-NASA Space Nuclear Propulsion Office and procurement policy is expected to be established within the next few months. "We are now evaluating what it will take to get the kind of fuel elements in the quantities we will need to meet our development program," a program official said in late August. "We intend to make the maximum utilization of private industry." LASL manufactured the fuel elements for the first three reactor experiments in the Kiwi series; then, with the stepped-up experimental program of the Kiwi-B series, Oak Ridge National Laboratory was called for fuel-element manufacture in support of LASL. Thus, a decision to use industrial firms for some or all of the engine-development elements would constitute industry's first fuel fabrication for the nuclear-rocket program.

Lewis Office. Finger has established a "branch" office at NASA's Lewis Research Laboratory to aid in the coordination of engine-development work carried out by the industry contractors, on the one hand, and by Lewis, on the other. Lewis has the principal NASA responsibility for research-development on nonnuclear components of the rocket engine (pumps, nozzle, etc.).

The Cleveland extension of Finger's office had about 15 persons last month, was expected to grow to about 30 by next June, and to as many as 100 eventually. Meanwhile, a similar, one-man extension office has been established at Albuquerque, N. M., and a third is likely at Jackass Flats (*see below*).

Test Facilities. Vitro Engineering Co. has been selected by NASA, subject to negotiation of a contract, to carry out architect-engineering on the first rocket-engine test facility at Jackass Flats, Nev. (NU, Aug. '61, 32). Twenty firms had submitted qualification bids on the facility—a maintenance, assembly and disassembly (MAD) building for conducting tests of engine-type development reactors. A construction start is expected next April for completion in mid-1963 at a cost of about $6-million.

AF Asks DOD to Seek SPUR Development at AEC

The Air Force has recently asked Harold Brown, assistant Defense Department secretary for research and engineering, to forward to AEC a request for development of a SPUR-type reactor—the "Space Power Unit, Reactor" under study by AiResearch div. of Garrett Corp. and Aerojet-General Nucleonics Corp. Providing Brown approves the request, AEC would be asked to develop SPUR or a similar reactor for use in auxiliary-power and/or electrical-propulsion systems in space. SPUR would use an alkali-metal, heat-exchanger system to produce 150-300 kw in its early stages and as much as 1,000 kw eventually. Both AEC and NASA have been active on high-temperature, liquid-metal systems for electrical and auxiliary power (NU, Feb. '61, 83) but NASA has been concentrating on basic materials research and AEC has not yet gotten into development of a reactor as large as the SPUR concept. Garrett feels a SPUR system could be ready for ground test by 1966.

NASA to Use Curium-242 Generators in Surveyor

In a quiet action ending months of uncertainty about the use of radioisotopic power in the Surveyor lunar-landing series, NASA has formally decided to use curium-242 generators in all but the first two of the five Surveyor spacecraft (NU Aug '61, 32). The thermoelectric generators will be used in the first two, as well, if available when these are launched. The series, requiring 15–25 watts per spacecraft, is scheduled to be carried out over the period 1963–66 to provide environmental data. Martin Co., under its year-to-year contract with AEC on isotopic-power technology, is developing the curium devices and believes it could deliver generators in time for the first and succeeding Surveyor spacecraft.

Fuel for the first curium generator is to be fabricated this fall and winter at Quehanna, Pa., after delivery of the radioactive material from AEC's Materials Testing Reactor, Idaho. The americium-241 capsules irradiated at MTR—to produce the alpha-emitting curium-242—were prepared by Martin at the AEC-funded Transuranic Elements Processing Facility, Baltimore, Md. Also under AEC contract, Martin is developing a thermionic converter of 5–8 watts using curium-242. Thermo Electron Engineering Co., Waltham, Mass., is subcontractor to Martin for the converter. NASA contractor for the Surveyor spacecraft is Hughes Aircraft Corp.

Meanwhile, NASA said it expected to let three study contracts on flight-test systems for SNAP-8—first nuclear-electric propulsion system—this fall; the studies would run six to nine months. SNAP-8 has this schedule: first 30-kw systems, using nonnuclear heat sources, to go into operation late this year; first reactor (60-kw rating) to go critical next year; first operation of entire engine system, late 1963; first flight test, early 1965.

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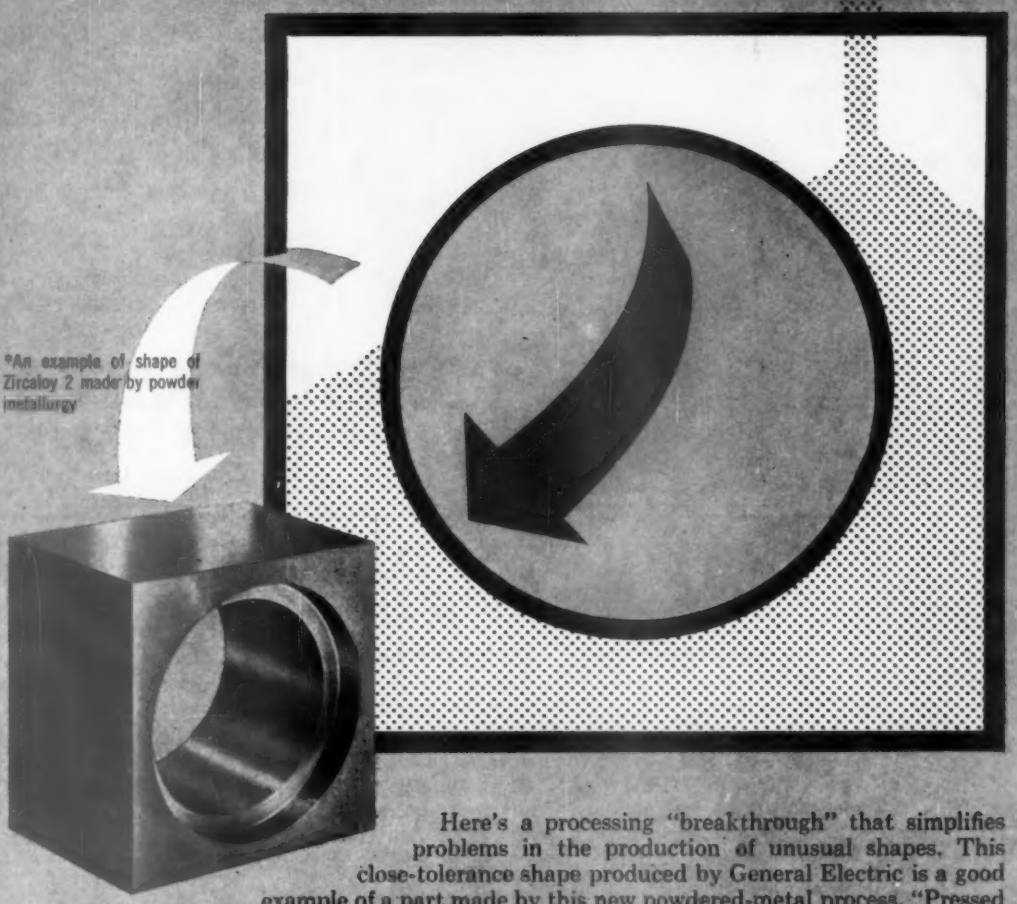

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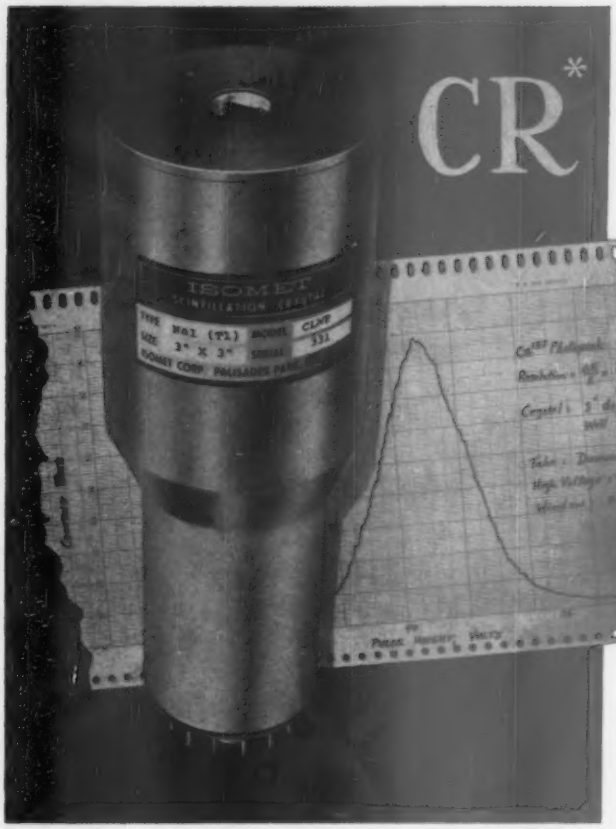

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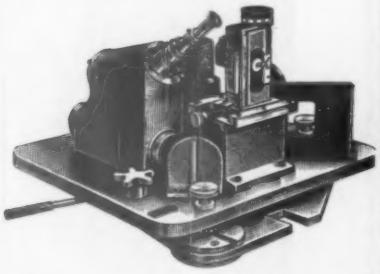

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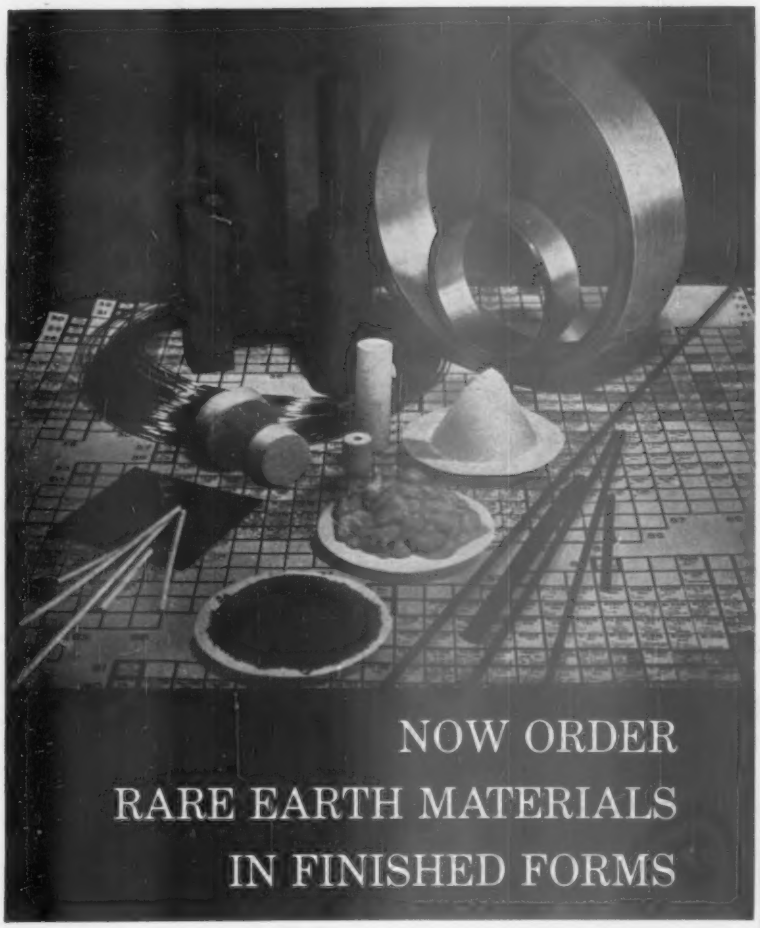

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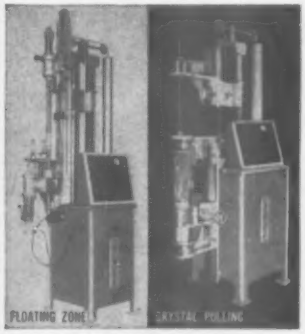

The Lepel Model HCP-D consists of the basic unit with the traverse mechanism and all the controls including the controls for the operation of the generator, and the floating zone and crystal pulling attachments. The same basic support, programming and control unit is used in either adaptation. The major variations are in the attachments and the induction coils. The change from one application to the other can be accomplished in a very short time.

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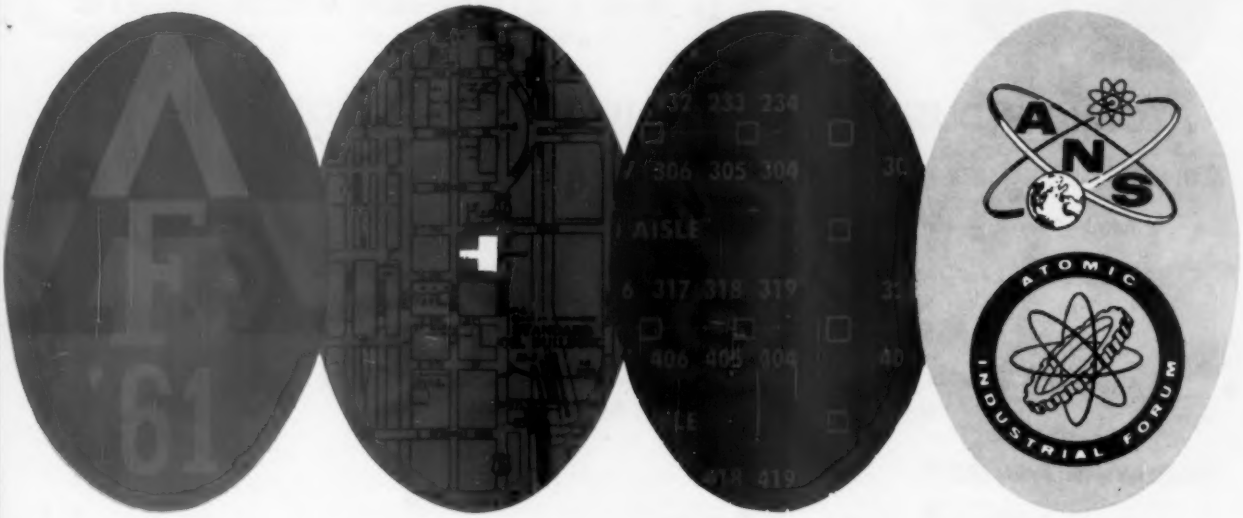

ATOMFAIR '61

OFFICIAL EXHIBITOR PROGRAM

From November 6th to 9th the Conrad Hilton Hotel in downtown Chicago will be the site of the 7th Annual AtomFair, jointly sponsored by the Atomic Industrial Forum and American Nuclear Society. Eighty-four exhibitors will display new products and services in the North and South Exhibit Halls on the third floor of the Conrad Hilton. In addition to the AtomFair Exhibit, meetings and activities of the American Nuclear Society and Atomic Industrial Forum will be held at the Conrad Hilton during AtomFair Week. The official AtomFair program and directory on the following pages lists the exhibitors and exhibits along with schedules for both the ANS and AIF meetings and activities.

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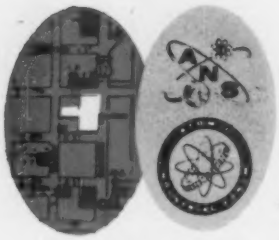

ANS/AIF MEETINGS

HELD DURING ATOMFAIR WEEK AT THE

ATOMIC INDUSTRIAL FORUM 1961 ANNUAL CONFERENCE

MONDAY—NOVEMBER 6

Morning Session—Nuclear Propulsion in Space Exploration—Waldorf Room

Luncheon Address—AEC–NASA Nuclear Space Program—Boulevard Room
Speaker: Rep. Melvin Price, Chairman of the Joint Congressional Committee's Sub-committee on Research and Development

Afternoon Session—Nuclear Power Sources for Communication Satellites—Beverly Room
Nuclear Power, Radiation and Isotopes—Waldorf Room

TUESDAY—NOVEMBER 7

Morning Session—Reactor Safety—Williford Room

Luncheon Address—ANS–AIF Luncheon—Boulevard Room
Speaker: E. M. Zuckert, Secretary, U. S. Air Force

Afternoon Session—Reactor Safety (continued)—Williford Room

WEDNESDAY—NOVEMBER 8

Morning Session—National Policy and Nuclear Progress—Williford Room

Afternoon Session—National Policy and Nuclear Progress (continued)—Williford Room

AMERICAN NUCLEAR SOCIETY 1961 WINTER MEETING

MONDAY—NOVEMBER 6

6:00–8:00 p.m.—Reception—Williford Room

TUESDAY—NOVEMBER 7

8:00 a.m.—Intersectional Breakfast—Private Dining Room 1

9:00 a.m.—Technical Sessions
Reactor Structural Materials (Special Session 5)—Lower Tower Room
Application of Critical Experiment Information to Design (Special Session 6)—Waldorf Room
Hot Laboratories for Research (HL Div. 11)—Upper Tower Room
Analysis and Applications (I&R Div. 17)—Bel Aire Room
Shielding I (S Div. 20)—Private Dining Room 4
Neutron Spectra and Thermal Cross Sections (Session 22)—Private Dining Room 2
Advanced Concepts and Direct Conversion Devices (Session 32)—Astoria Room

12:00 noon—ANS–AIF Luncheon—Boulevard Room
Speaker: E. M. Zuckert, Secretary, U. S. Air Force

2:00 p.m.—Distinguished Lecturer's Address—Normandie Lounge
Speaker: H. J. Bhabha, Chairman, Indian AEC (Special Session 1)

SCHEDULE

CONRAD HILTON HOTEL

3:00 p.m.—Technical Sessions
- Computational Aspects of Reactor Kinetics (Special Session 9)—Lower Tower Room
- Panel Discussion: Space Radiation and its Shielding (Special Session 10)—Waldorf Room
- Glove and Shielded Boxes (HL Div. 12)—Upper Tower Room
- Measurement and Counting Techniques (I&R Div. 18)— Bel Aire Room
- Reactor Depletion and Burnup (Session 26)—Private Dining Room 4
- Irradiation Damage and In-pile Testing (Session 33)—Private Dining Room 2
- Chemistry and Processing (Session 36)—Astoria Room

7:30 p.m.—Shielding Division, Informal Session—Waldorf Room

WEDNESDAY—NOVEMBER 8

9:00 a.m.—Technical Sessions
- Recent Advances in Spent-Reactor-Fuel Processing (Special Session 3)—Waldorf Room
- Power Reactor Operational and Maintenance Experience (Special Session 7)—Lower Tower Room
- General-Purpose Manipulators (HL Div. 13)—Upper Tower Room
- Shielding II (S Div. 21)—Private Dining Room 4
- Resonance Integrals and Conversion Ratios (Session 23)—Astoria Room
- Critical Experiments I (Session 27)—Private Dining Room 2

2:00–2:30 p.m.—Hot Lab Division Business Meeting—Upper Tower Room

2:00 p.m.—Technical Sessions
- Operation of Reactor Facilities on the University Campus (Special Session 8)—Waldorf Room
- Computer Codes and Reactor Analysis (RM&C Div. 19)—Private Dining Room 4
- Critical Experiments II (Session 28)—Private Dining Room 2
- Heat Transfer and Fluid Flow (Session 37)—Astoria Room

2:30 p.m.—Hot-Laboratory Operations and Equipment (HL Div. 14)—Upper Tower Room

6:30 p.m.—ANS–AIF Reception—Grand Ball Room Assembly

7:30 p.m.—ANS–AIF Banquet—Grand Ball Room
- Speaker: Glenn T. Seaborg, Chairman U. S. AEC

THURSDAY—NOVEMBER 9

9:00 p.m.—Technical Sessions
- Radioactivity in the Atmosphere (Special Session 2)—Waldorf Room
- Special-Purpose Hot Laboratories and Facilities (HL Div. 15)—Grand Ball Room East
- Neutron Age and Diffusion Length (Session 24)—Williford Room A
- Reactor Dynamics and Stability (Session 29)—Williford Room B
- Nuclear Design of Shippingport PWR Core 2 (Session 30)—Williford Room C
- Reactor Fuel Materials I (Session 34)—Grand Ball Room Assembly

2:00 p.m.—Technical Session
- Transfer Systems and Shielding Windows (HL Div. 16)—Grand Ball Room East
- Reactor Physics Analysis (Session 25)—Williford Room A
- Instrumentation and Control (Session 31)—Williford Room B
- Reactor Fuel Materials II (Session 35)—Williford Room C
- General Reactor Engineering (Session 38)—Waldorf Room

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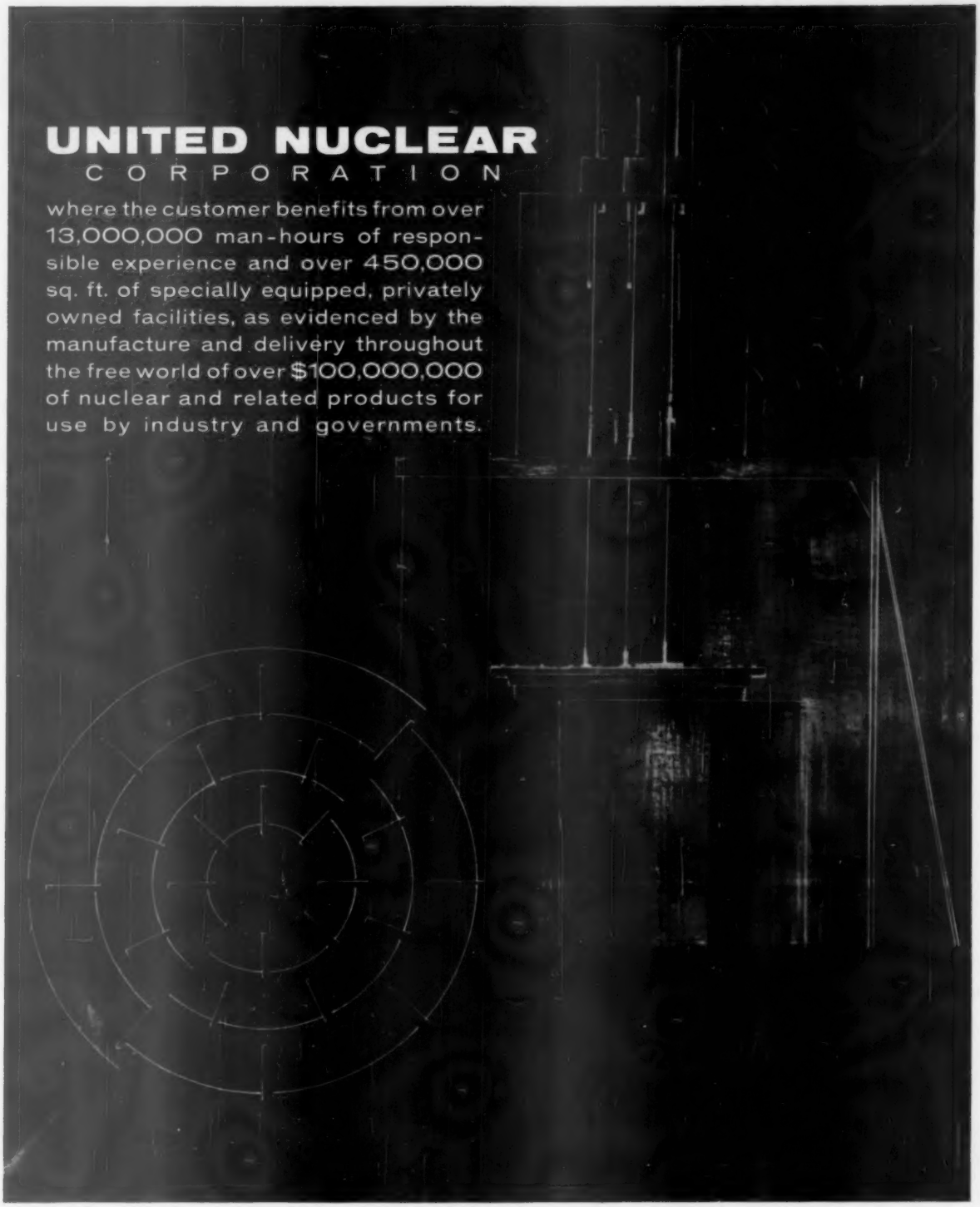
ATOMFAIR FILM SCHEDULE

Running Time (min)	Title and Exhibitor	Exhibit Time
MONDAY, NOVEMBER 6		
57	Industrial Application of Radioisotopes (U. S. AEC)	10:30 a.m.
13	Heart for Yankee (Westinghouse)	11:27 a.m.
30	Atomics International Film	11:40 a.m.
17	High Energy Radiations for Mankind (High Voltage)	12:10 p.m.
25	Fume Hood Design (Kewaunee)	12:27 p.m.
18	Modern Remote Handling (General Mills)	12:52 p.m.
27	Atomic Venture (General Electric)	1:10 p.m.
17	Conoseal Joints (Aeroquip)	1:37 p.m.
25	Magic Hands of AMF (AMF Atomics)	1:54 p.m.
18	Reaching for the Stars (General Atomic)	2:19 p.m.
28	Florida—Profile of Progress (Fla. Dev. Comm.)	2:37 p.m.
20	Technical Information Services of AEC (U. S. AEC)	3:05 p.m.
13	Heart for Yankee (Westinghouse)	3:25 p.m.
30	Atomics International Film	3:38 p.m.
17	High Energy Radiations for Mankind (High Voltage)	4:08 p.m.
25	Fume Hood Design (Kewaunee)	4:25 p.m.
27	Invitation to Kentucky (Commonwealth of Ky.)	4:50 p.m.
TUESDAY, NOVEMBER 7		
57	Industrial Application of Radioisotopes (U. S. AEC)	10:30 a.m.
18	Modern Remote Handling (General Mills)	11:27 a.m.
27	Atomic Venture (General Electric)	11:45 a.m.
17	Conoseal Joints (Aeroquip)	12:12 p.m.
25	Magic Hands of AMF (AMF Atomics)	12:29 p.m.
18	Reaching for the Stars (General Atomic)	12:54 p.m.
28	Florida—Profile of Progress (Fla. Dev. Comm.)	1:12 p.m.
20	Technical Information Services of AEC (U. S. AEC)	1:40 p.m.
13	Heart for Yankee (Westinghouse)	2:00 p.m.
30	Atomics International Film	2:13 p.m.
17	High Energy Radiations for Mankind (High Voltage)	2:43 p.m.
25	Fume Hood Design (Kewaunee)	3:00 p.m.
18	Modern Remote Handling (General Mills)	3:25 p.m.
27	Atomic Venture (General Electric)	3:43 p.m.
17	Conoseal Joints (Aeroquip)	4:10 p.m.
25	Magic Hands of AMF (AMF Atomics)	4:27 p.m.
27	Invitation to Kentucky (Commonwealth of Ky.)	4:52 p.m.
WEDNESDAY, NOVEMBER 8		
57	Industrial Application of Radioisotopes (U. S. AEC)	10:30 a.m.
18	Reaching for the Stars (General Atomic)	11:27 a.m.
28	Florida—Profile of Progress (Fla. Dev. Comm.)	11:45 a.m.
20	Technical Information Services of AEC (U. S. AEC)	12:13 p.m.
13	Heart for Yankee (Westinghouse)	12:33 p.m.
30	Atomic International Film	12:46 p.m.
17	High Energy Radiations for Mankind (High Voltage)	1:16 p.m.
25	Fume Hood Design (Kewaunee)	1:33 p.m.
18	Modern Remote Handling (General Mills)	1:58 p.m.
27	Atomic Venture (General Electric)	2:16 p.m.
17	Conoseal Joints (Aeroquip)	2:43 p.m.
25	Magic Hands of AMF (AMF Atomics)	3:00 p.m.
18	Reaching for the Stars (General Atomic)	3:25 p.m.
28	Florida—Profile of Progress (Fla. Dev. Comm.)	3:43 p.m.
20	Technical Information Services of AEC (U. S. AEC)	4:11 p.m.
13	Heart for Yankee (Westinghouse)	4:31 p.m.
17	High Energy Radiations for Mankind (High Voltage)	4:43 p.m.
27	Invitation to Kentucky (Commonwealth of Ky.)	5:00 p.m.
THURSDAY, NOVEMBER 9		
57	Industrial Application of Radioisotopes (U. S. AEC)	10:30 a.m.
30	Atomic International Film	11:27 a.m.
25	Fume Hood Design (Kewaunee)	11:57 a.m.
18	Modern Remote Handling (General Mills)	12:22 p.m.
27	Atomic Venture (General Electric)	12:40 p.m.
17	Conoseal Joints (Aeroquip)	1:07 p.m.
25	Magic Hands of AMF (AMF Atomics)	1:24 p.m.
18	Reach for the Stars (General Atomic)	1:49 p.m.
28	Florida—Profile of Progress (Fla. Dev. Comm.)	2:07 p.m.
20	Technical Information Services of AEC (U. S. AEC)	2:35 p.m.
13	Heart for Yankee (Westinghouse)	2:55 p.m.
17	High Energy Radiations for Mankind (High Voltage)	3:08 p.m.
30	Atomic International Film	3:25 p.m.
25	Fume Hood Design (Kewaunee)	3:55 p.m.
18	Modern Remote Handling (General Mills)	4:20 p.m.
27	Atomic Venture (General Electric)	4:38 p.m.
27	Invitation to Kentucky (Commonwealth of Ky.)	5:05 p.m.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1961 AIF PROGRAM ACTIVITIES

The Atomic Industrial Forum, the only membership association exclusively concerned with the commercial development of atomic energy, serves its members in two principal ways. First, through the monthly "Memo to Members"—an interpretative review and analysis of atomic-energy events, policies and programs—and through a variety of other publications, the Forum keeps its members informed on matters bearing on their interests and involvement in atomic-energy development and application. Second, through the identification, study and resolution of industry-wide problems, the Forum contributes to the creation of an environment in which industry can participate in the development and commercial application of atomic energy under a system of free competitive enterprise.

In carrying out the second of these two major responsibilities, the Forum supplements its limited staff resources by extensive use of the special skills and backgrounds of its diverse membership—principally through membership committees. Outlined below are some of the 1961 program activities in which the Forum has been and is currently engaged.

Committee Activities

National Policy on Peaceful Atomic Energy. One of the principal actions taken by the Forum Board of Directors in 1961 was to set up a Committee on National Policy on Peaceful Atomic Energy under the chairmanship of Chauncey Starr, President of Atomics International, to develop the views of the atomic industry on goals for this nation's peaceful atomic-energy activities and the paths that should be followed to attain these goals. Serving with Dr. Starr on this important committee are: William Clapp of Florida Power Company, Lauchlin Currie of The Babcock & Wilcox Company, W. Kenneth Davis of Bechtel Corporation, Lyman Fink of General Electric Company, Elmer Lindseth of Cleveland Electric Illuminating Company, Eger Murphree of Esso Research & Engineering Company, Harold Quinton of Southern California Edison Company, Oscar Ruebhausen of Debevoise, Plimpton & McLean, John Simpson of Westinghouse Electric Corporation and Philip Sporn of American Electric Power Service Corporation.

The Committee's study, which is focusing principal attention on civilian nuclear power, nuclear-space applications, maritime propulsion and the industrial use of radiation and isotopes, has three principal objectives: (1) to develop a technological and economic delineation of a set of program goals, (2) to present a plan, involving both technical and financial considerations, through which the private and government sectors of our economy may meet these goals and (3) to suggest possible modifications in the Atomic Energy Act of 1954, as well as changes in government policies and administrative procedures that will be needed to support recommended programs. A major portion of the program agenda for the 1961 Forum Annual Conference will relate to the work of this Committee.

Contract Practices. This committee, which until recently was chaired by Roy M. Casper of Allis-Chalmers Manufacturing Company, has concentrated most of its attention during 1961 on two cost principles of AEC contracting policies and procedures—those related to bidding and proposal costs and those concerned with incentive compensation. The Committee's work in this area has been the primary responsibility of a Subcommittee on Cost Principles which includes among its members: Roy Casper, J. B. Ferguson of Westinghouse Electric Corporation, George Frost and W. C. Gaygan of General Electric Company, Oscar Gray of Nuclear Materials and Equipment Corporation, Walter Hamilton and Edward Savage, Jr., of United Nuclear Corporation, Ross Macaulay of The Martin Company, Henry Nickel of Allis-Chalmers Manufacturing Company and Raymond Woodrow of Princeton University. Committee recommendations on these two cost principles that were formulated and sent to the AEC are reflected in AEC's revised contract cost principles published in August.

Reactor Safety. The 1961 activities of this Committee under the chairmanship of W. Kenneth Davis, Vice-President of Bechtel Corporation, have largely been concentrated on problems of reactor siting. Following review of the AEC's proposed site-criteria guides published in February, the Committee determined that it might be most helpful to incorporate its comments in the form of a revised version of the proposed regulation. The suggested revised guides were forwarded to the AEC in June and subsequently served as the basis for a statement by the Committee Chairman at hearings on radiation safety and regulation of the Joint Congressional Committee on Atomic Energy and for a meeting with AEC representatives.

Members of the working group that formulated the revised guides included: Roger Coe of Yankee Atomic Electric Company, Kenneth Davis, James F. Fairman of Consolidated Edison Company of New York, John Gray of Nuclear Utility Services, Inc., Woodrow E. Johnson of Westinghouse Electric Corporation, D. Roy Shoults of General Electric Company and Harold Vann of Jackson & Moreland, Inc. Plans call for making reactor safety a principal program topic for the 1961 Forum Annual Conference in November.

Mining and Milling. This committee was set up in 1961 under the chairmanship of Richard S. Newlin, Vice-President for Operations of Anaconda Company, to consider a variety of problems relating to the supply of uranium concentrates to meet government purchase programs, as well as

(Continued on page H)

nongovernment and international requirements. Initial Committee attention is being focused on those problems related to the development by the AEC of uranium purchase policies for the period following 1966.

Other matters with which the Committee is concerned are: workmen's compensation, radiation protection in uranium mines and mills and the effect of depleted uranium on future markets for natural uranium. Assisting in the guidance of the Committee is a steering group, which in addition to Newlin, includes: Vice Chairman A. Payne Kibbe, President of Hidden Splendor Mining Company, George H. Cobb of Kermac Nuclear Fuels Corporation, William B. Hall of Vitro Corporation of America, Mitchell H. Kline of Rare Metals Corporation of America, Mitchell Melich of Uranium Reduction Company, A. V. Quine of Utah Construction and Mining Company and Ross A. Thomas of Phillips Petroleum Company.

Fuel Availability Overseas. Consultant Kenneth D. Nichols, a former AEC General Manager, is serving as chairman of a recently formed Committee on Fuel Availability Overseas to elicit industry views on establishing government assurances as to long-term availability of enriched fuels for overseas reactors. The Committee was set up following an exchange of correspondence between Forum President Charles H. Weaver and AEC Chairman Glenn T. Seaborg.

The Forum pointed out to the AEC that during the past several months industry and government representatives in both Europe and the Far East have called attention to the problem of assuring continued supplies of fuel for enriched-reactor systems and to the fact that there appears to be a need for longer-term agreements and greater flexibility and simplicity in fuel-supply policies and procedures. In response the AEC said that it would welcome the suggestions of the American nuclear industry on how to attain this objective. The Committee is expected to send its recommendations to the AEC before the end of the year.

Public Understanding. This committee, which is concerned with the large and inherently diffuse problem of achieving better public understanding and hence public acceptance of atomic-energy activities, is chaired by Oliver Townsend, Director of the New York State Office of Atomic Development. The Committee, through the coordinated efforts of three subcommittees, is currently working on the preparation of a fact book designed to present for the general public in a straightforward and meaningful way the benefits and hazards associated with atomic-energy development. The subcommittees and their chairmen are: Research—Joseph Dukert of The Martin Company; Evaluation—Jack Healy of General Electric Company; and Dissemination—Ashton O'Donnell of Stanford Research Institute.

International Liability. This committee, under the chairmanship of D. Roy Shoults of General Electric Company, is actively following and in some instances assisting in the formulation of liability conventions by such groups as Euratom, OEEC and IAEA, as well as those of individual countries in Europe and the Far East. Earlier this year, the Committee prepared two draft memoranda to assist in developing the U. S. position at the Diplomatic Conference on Maritime Law in Brussels on an international convention determining the liability of nuclear-ship operators.

Insurance and Indemnity. This committee has a longer record of continued service than any other Forum Committee. Among its 1961 activities, the Committee, which is chaired by Arthur F. Williams of Consolidated Edison Company of New York, prepared and sent to the AEC recommendations that reactor-fuel fabricators and processors be afforded indemnity protection provided under the terms of the Price-Anderson amendments to the Atomic Energy Act of 1954. The Committee is currently examining the need for insurance protection against liability for damage to nuclear-reactor systems and other on-site property.

Workmen's Compensation. This Forum committee, under the chairmanship of Herzel H. E. Plaine of the law firm of Rhyne and Rhyne, has undertaken an analysis of the problems involved in assuring adequate and fair compensation to workers for disabilities resulting from occupational exposures to radiation. The Committee has prepared and published an analysis of two problems of general interest to the nuclear industry: (1) the time limits specified by some state workmen's compensation laws for the emergence of compensable occupational diseases, and (2) proof of causal relationship between an injury or disease and the occupational exposure to radiation.

Federal-State Relations. This committee, under the chairmanship of Arvin Upton, a partner in the law firm of LeBoeuf, Lamb and Leiby, is studying and analyzing the 1959 amendment to the Atomic Energy Act of 1954 that permits the AEC to transfer to individual states certain materials licensing and regulatory responsibilities. Although the Committee is primarily concerned with the impact on industry anticipated by such transfers of responsibility, it is currently concentrating its attention on the identification and resolution of those problems that have to date impeded the delegation of responsibilities to the states.

Patents. The recommendations of this committee, chaired by Lee L. Davenport of Sylvania Electric Corporation, have been of assistance to the AEC in its review and modification of policies on the filing of foreign patent rights by AEC contractors. A subcommittee, under the chairmanship of John Howland of Westinghouse Electric Corporation, is currently studying the problem of acquisition of background patents by the AEC under AEC contracts.

Nuclear Standards. The Forum, under the guidance of its Committee on Codes and Standards chaired by William Shoupp, Technical Director of the Atomic Power Department of Westinghouse Electric Corporation, sponsors two sectional committees—N-2 on General and Administrative Standards and N-7 on Radiation Protection—of the American Standards Association Nuclear Standards Board. Sectional Committee N-7, under the chairmanship of Remus McAllister of Liberty Mutual Insurance Companies, prepared a standard which in 1961 was published as an ASA Nuclear Standard for protection of workers in uranium mines and mills.

Uniform State Liability Act. A Working Group, chaired by Arthur W. Murphy of the law firm of Baer, Marks, Friedman & Berliner, has worked extensively in modifying and redrafting an act proposed by William J. Pierce of the University of Michigan Law School which would impose "liability without fault" on reactor operators for injuries and damages arising out of reactor operations. Among the changes suggested by the Group was the recommendation that the proposed act be applicable only to those incidents covered by the Price-Anderson indemnification provisions of the Atomic Energy Act. The redrafted act was rejected at the July National Conference of Commissioners on Uniform State Laws as a "uniform state law" but approved as a "model state act."

Other Activities

AEC Regulatory Organization. In April, the Forum sponsored a seminar to discuss various proposals for modifying the AEC's regulatory organization and procedures. Seminar participants included James H. Campbell of Consumers Power Company, James F. Fairman of Consolidated Edison Company of New York, Lyman R. Fink of General Electric Company, Lee M. Hydeman of the University of Michigan, Murray Joslin of Commonwealth Edison Company, Oscar M. Ruebhausen of Debevoise, Plimpton & McLean, George F. Trowbridge of Shaw, Pittman, Potts and Trowbridge, Arvin E. Upton of LeBoeuf, Lamb & Leiby and Charles Weaver of Westinghouse Electric Corporation. Although the seminar was not designed to produce a consensus, there was general agreement with the recommendations of a study conducted by the staff of the Joint Congressional Committee on Atomic Energy for establishment of a three-member Licensing Board with authority to grant all AEC licenses.

Communication Satellites. The Forum recently sponsored a seminar on the application of isotopic and nuclear-reactor devices as electric-power sources for communication satellites. The seminar was held to discuss national goals and appropriate timetables for the development of nuclear-powered communication satellites. Participants included Representative Melvin Price of the Joint Congressional Committee on Atomic Energy, Atomic Energy Commissioner Leland Haworth, Deputy Director Hugh Dryden of the National Aeronautics and Space Agency, other officials of the AEC, NASA, National Space Council, President's Science Advisory Committee, State Department and Federal Communications Commission and representatives of a number of industrial firms active in the development of such nuclear applications. This is the first of what is expected to be an increasing number of Forum program activities related to nuclear applications in space.

Reactor Fuel Ownership. The Forum recently held a seminar to discuss with representatives of the AEC possible transition measures if special nuclear materials were to be transferred from government to private ownership. The AEC indicated in May that it is considering whether to recommend amendments to the Atomic Energy Act to eliminate the statutory requirement for government ownership.

AIF-JAIF Nuclear Power Conference. The Forum will cosponsor later this year with the Japanese Atomic Industrial Forum a four-day conference in Tokyo on nuclear power that will place particular emphasis on U. S. experience in designing, building and operating central-station nuclear-power plants. The conference will also highlight such other topics as third-party liability, reactor siting, and nuclear-fuel availability, with a view to increasing industry-to-industry cooperation through the two Forums. A number of top-level representatives of U. S. industry and government will participate in the conference scheduled for December 5–8.

Business statistics. The Forum is continuing the program initiated last year to collect, compile and publish sales statistics on atomic-energy systems, components and services, as well as statistics on research and development expenditures and capital investment in atomic energy facilities.

Available Publications

A Uniform Procedure for Use in the Evaluation of Nuclear Power Reactors, September, 1959: a manual for presenting design data pertaining to reactors under evaluation, to outline their anticipated cost performances and to describe both the current state of their development and additional developmental requirements.

Business Statistics on the Atomic Industry—1954–1958, June, 1960: an industry-wide survey of nuclear product and service sales, nuclear-research and development expenditures, private capital investments and personnel employment.

The Role of Nuclear Propulsion in Merchant Shipping, June, 1960: proceedings of a conference sponsored by the Forum in Philadelphia, Pa., April 28–30, 1960, in cooperation with the AEC and the Maritime Administration.

Proposed AEC Criteria for State Radiation Control Programs, September, 1960: prepared by the Forum Committee on Federal-State Relations.

Atoms for Industry World Survey, September, 1960: collection of articles by more than 20 international nuclear authorities on status and prospects for commercial applications of atomic energy on a world-wide basis.

Report of the Forum Ad Hoc Committee on International Nuclear Liability and Insurance, December, 1960: outlines governmental and intergovernmental programs for financial protection against nuclear hazards.

Price-Anderson Indemnification for Fuel Fabricators and Processors, January, 1961: a statement of considerations for an extension of indemnification protection prepared by an ad hoc group of the Forum Committee on Insurance and Indemnity.

Memorandum and Supplementary Memorandum to Interdepartmental Committee on Nuclear Ship Liability Convention, February, 1961: prepared under the auspices of Forum Ad Hoc Committee on International Nuclear Liability and Insurance.

Nuclear Frontiers—1960, March, 1961: proceedings of Forum's Seventh Annual Conference, San Francisco, California, December 11–16, 1960; includes papers and discussion on the role of nuclear energy in space exploration and uranium production, the IAEA program, public understanding and acceptance of atomic activities, policy and procedural problems, nuclear developments abroad, problems in initiating a power-reactor project, nuclear-fuel cycle, international atomic-energy contracts, advanced nuclear projects and new radiation and radioisotope applications.

AEC Regulatory Organization and Processes, April, 1961: a summary of a Forum seminar on this topic including proposals for certain organizational and procedural modifications.

Report of AIF Ad Hoc Committee on Workmen's Compensation, June, 1961: discusses compensation for disability or death resulting from injury to employees exposed to radioactive materials.

Reactor Site Criteria, June, 1961: includes (1) AEC proposed guides (10 CFR 100) published in the Federal Register for February 11; (2) redraft of the proposed guides prepared by a working group of the Forum Committee on Reactor Safety; (3) an appendix of four example calculations including the calculation incorporated in the AEC proposed guides; (4) comparison of AEC and Forum proposals; and (5) statement prepared by Committee Chairman W. Kenneth Davis for JCAE hearings on radiation safety and regulation.

Statement to the AEC re the Domestic Uranium Industry, June, 1961: a background paper which served as the basis of a discussion between representatives of the Forum Committee on Mining and Milling and the AEC.

Progress Chart: U. S. Nuclear Power Projects, 4th edition, September, 1961: shows present status of and industrial participation in nuclear-power projects in the U. S. and abroad.

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Model 8250 Spectrometer incorporating the All-Electronic Scaler Model 135, the Model 250 Amplifier-Analyzer and Model F-8 Fan Filter Assembly.

Baird-Atomic announces the new Model 8250 single channel Spectrometer which can be quickly and easily calibrated in energy units (Mev) for any energy range from X-rays to cosmic rays. Spectra can be positioned as desired by the high voltage and the gain controls. Any degree of differential operation (relative window width) or integral operation may be obtained.

The Model 8250 is a combination of two instruments just added to the Baird-Atomic line. They are the Model 250 Amplifier-Analyzer and a new all-electronic Model 135 Scaler. The Scaler, which combines a 5 decade, 5 micro-second scaler and an electronic timer on one chassis, is excellent for both general lab counting work and for use with the most sophisticated automatic sample changing systems.

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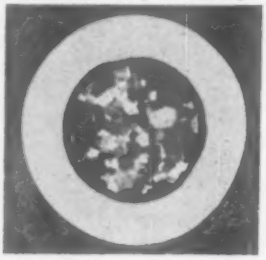
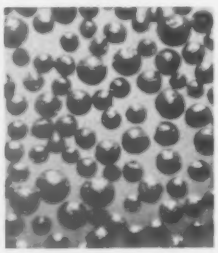
Fueled Microspheres bring new efficiency and economy to all nuclear reactor fuels!

Better reactor fuel elements at lower costs are here with 3M's new uranium dicarbide Fueled Microspheres! This radically new UC_2 Microsphere may be protected by a pyrolytic carbon coating (see picture, right). Result: retention of fission products in fuel particles is improved, fuel element life extended; more of the uranium fuel material can be utilized before the nuclear fuel element must be reprocessed.



The spherical shape of 3M Fueled Microspheres results in greater strength (see picture, left). This gives them distinct advantages over particles of irregular shape . . . greater strength and minimum surface area. Their fracture resistance reduces particle breakup during fabrication of fuel elements composed of fuel particles dispersed in inert matrices.



The minimal surface area of Microspheres lessens reaction between fuel particles and matrix materials. Reduction of atmospheric reaction facilitates handling—Microspheres are less pyrophoric than irregular particles of high surface area. For their surface area they offer greater concentration of uranium; make possible a more uniform dispersion of fuel particles in fuel element matrices, and resist stringering in metal matrices.

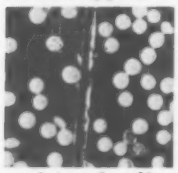
3M offers Fueled Microspheres in any size range within 30 to 500 micron limits. Prices are competitive with uranium oxide spherical particles. For information, please fill out the coupon.

Magnified 1000X, this illustration shows cross sections of Microspheres of UC_2. Visually, they appear in many different colors, depending on the metallographic treatment.

in fuel and isotope technology

Radiating Microspheres offer assured safety to radioisotope applications!

Now, for the first time . . . successful, safe containment of radioactive isotopes! 3M Radiating Microspheres achieve this breakthrough with small ceramic particles about the diameter of a human hair (see picture, below) that impound radioactive materials for new applied radiation safety...in military, industrial, and medical fields.



Convincing proof of the complete safety of 3M Radiating Microspheres: they can actually be introduced internally into the human body for medical therapy! 3M Microspheres "cage" a wide variety of radioactive isotopes in safe, non-reacting ceramic particles . . . physically isolate them from their environment while allowing the radiation to escape. Biologically dangerous isotopes are shackled, cannot react—even at extreme temperatures.

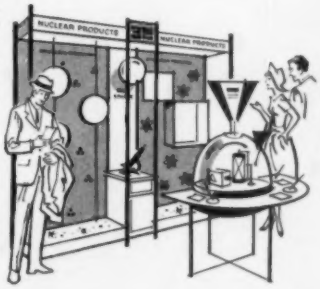
Self-luminous materials made with 3M Radiating Microspheres offer safer, longer-lasting brightness than a radium-activated source! Health hazards are minimized. If ingested, the Microspheres pass through the body without losing measurable amounts of the radioactive element. External radiation from the self-luminous devices is low. Useful life of a self-luminous source made with Pm-147 Microspheres is about five years.

Radiation sources made with 3M Radiating Microspheres offer a unique combination of desirable properties: unparalleled isotope retention at extreme temperatures and in the most corrosive environments . . . a wide variety of isotopes—many available in high specific activities—point, line, area, and volume configurations. An outstanding example of 3M source technology is the triply encapsulated Sr-90 beta source (see picture, right)

. . . a device which utilizes three distinct safety barriers: the Microsphere itself (1), a hermetically sealed stainless steel tube (2), and a ceramic overcoat (3). Traditional devices are rendered obsolete by this source which can retain the radioisotope at 1000°C.

Medical work to date indicates a wide variety of possible diagnostic, therapeutic, and experimental applications of 3M Radiating Microspheres in the life sciences.

Applications in the field of cancer therapy are currently being evaluated on a limited experimental basis.



At "The Atom Show" be sure to see the 3M Nuclear Products display, November 6-9, the Conrad-Hilton, in Chicago.

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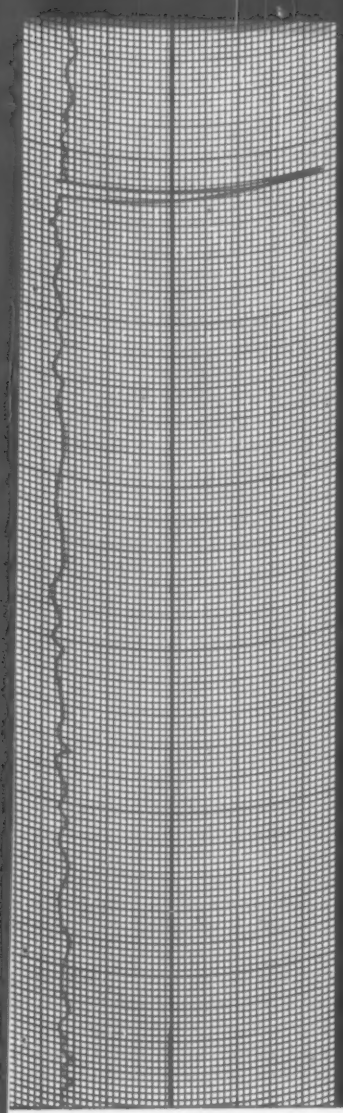

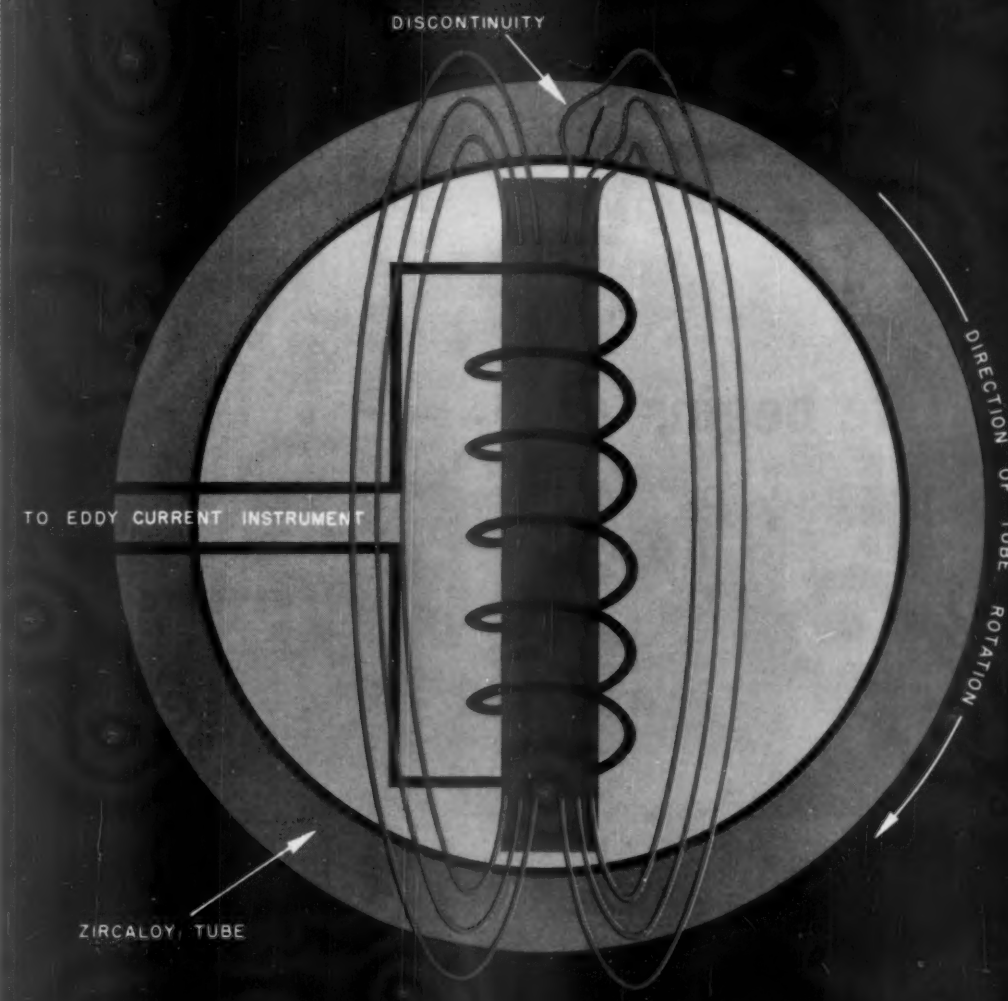

EDDY CURRENT PROBES INSIDE STORY ON PATHFINDER FUEL ELEMENT TUBING

Revealing the inside story on 60,000 tubes for the Pathfinder Reactor assured freedom from cracks greater than 10% of wall thickness on inside diameter.

This schematic end view of a rotating tube and the inserted probe illustrates the eddy current paths. When an inside diameter surface or subsurface discontinuity passes over the probe, changes occur in the electrical value of the coil (impedance). A corresponding change in voltage and current flow within the coil is converted and fed to the chart recorder (left). This probe provides 100% non-destructive testing of the zircaloy tubing.

This is an example of quality control applied to Pathfinder fuel elements being manufactured by Metals & Controls Inc., a corporate division of Texas Instruments Incorporated for the Allis Chalmers Manufacturing Company. Similar quality control methods and complete laboratory facilities of our M & C Nuclear Products group are ready to work for you to insure complete integrity of components for your nuclear projects. Our colorful booklet, "Fuels of the Future," is available on request from department NU-10.

This semi-automatic, non-destructive test apparatus, devised by T.I.'s scientists, rotates tubing while electronic probe is inserted.

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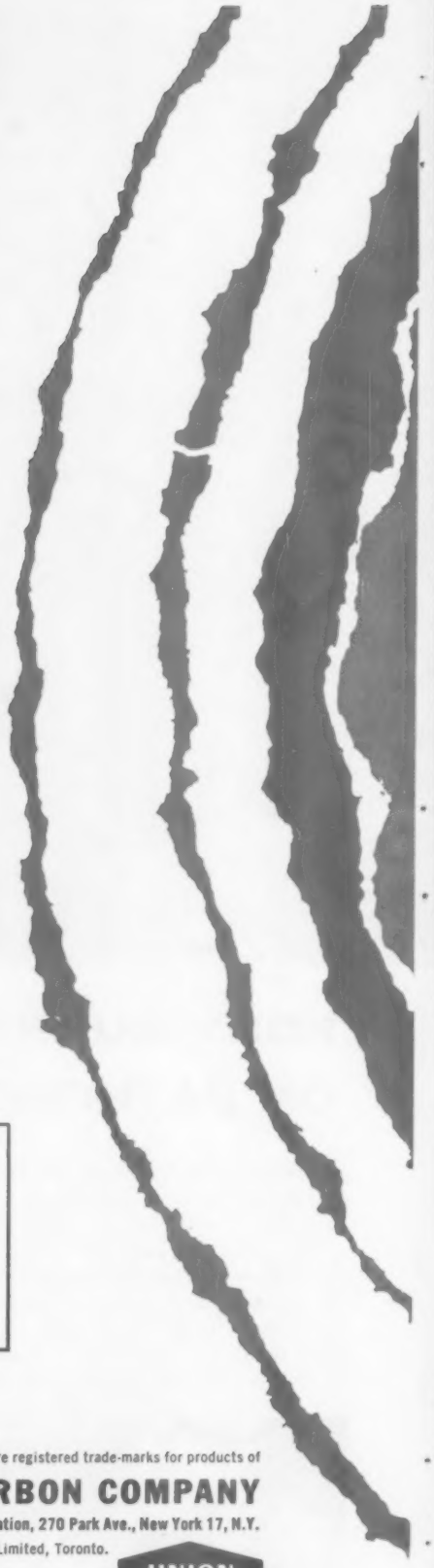

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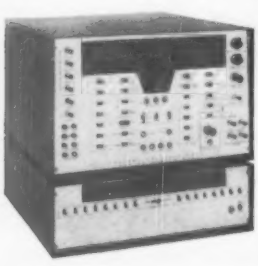
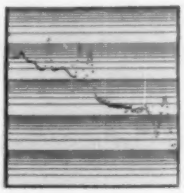
* In radiation analysis, accumulation of the energy distribution curve is usually followed by quantitative interpretation of the results. The most frequent first step in the interpretation is the determination of the intensity of individual lines by integration of the areas involved. With *FAST*, the operator selects a region of interest, depresses a switch, and the area of the selected region is quickly indicated in memory channel number one. The answer is then typed out by means of the IBM computer readout typewriter. Other regions of interest may be quickly integrated in the same manner. Answers are exact, and operation is simple and dependable. This is *FAST*. (Fast Area Sub-Totalling.)



MODEL ND-130A ANALYZER-COMPUTER

The Model ND-130A includes the analysis and summation circuitry (FAST) as well as spectrum stripping circuitry. It costs no more than the superb Model ND-130.



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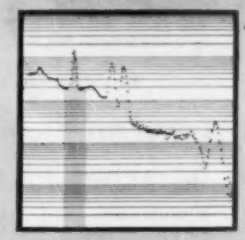
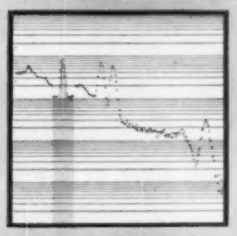


Step 1: Analyze the unknown radiation source. Correct for background counts, if desired, by utilizing the data reduction controls.



Step 2: Select any region of the spectrum by simple switch operations. The selected regions are displaced for instant visual examination. The channel numbers involved are indicated exactly by the switch settings.

Step 3: Depress the "initiate computer cycle" button. The sum of all data points in the selected region, only, is accumulated in a second or two. The sum, divided by ten if desired in order to avoid count overflow, is recorded into analyzer channel number one.

Step 4: Read out the answer in channel one by means of the IBM computer readout typewriter.
That's all. No more tedious adding machine operations. No more adding errors.

Precision of analysis and instrument dependability are nothing less than remarkable in the ND-130 series analyzers. For example, of sixty units delivered prior to July, all except one (probably damaged during installation) have operated without failure up to that date. No other analyzer model has ever approached this record. Almost flawless performance, combined with such features as punched tape read-in and read-out, internal data reduction, fast area sub-totalling, precision logarithmic curve display, and others, make this analyzer the best in the field.

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Model D rugged-duty Master-slave Manipulator

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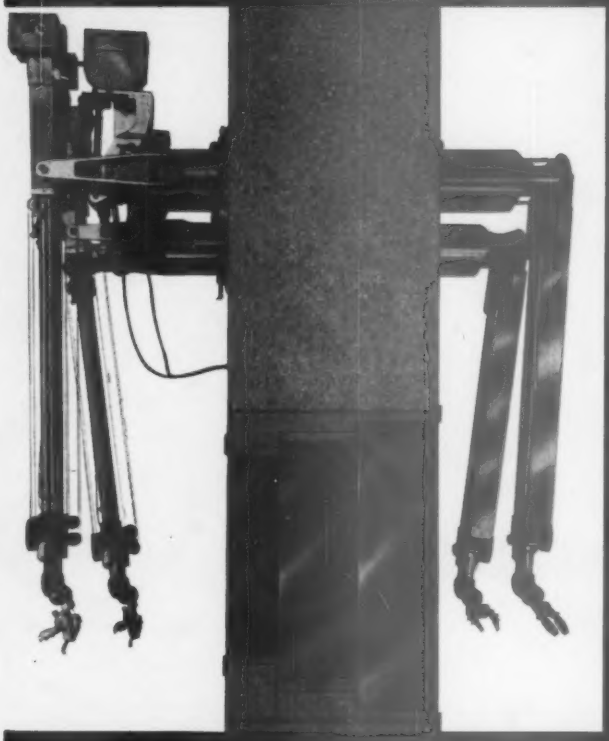
Load capacities at tong tips with fully extended boom tube:

- X motion—100 pounds
- Y motion—100 pounds
- Z motion—100 pounds

elevation rotation—50 pound feet
azimuth rotation—50 pound feet
twist-rotation—40 pound feet
gripping force and handling capacity—100 pounds



FEATURES—

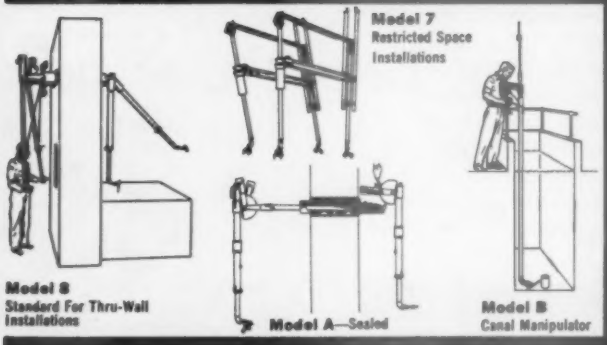
The Model D manipulator is a very rugged modification of the Model 8—a well-known and widely-used manipulator designed and first manufactured by Central Research.

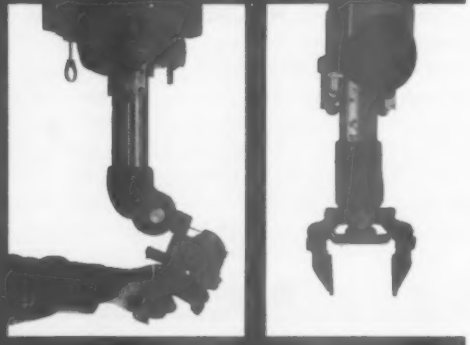
Unique new features of the Model D include: a new wrist joint with sturdy stainless steel gears and a twofold increase in gear ratio; stainless steel boom and counterweight tubes; high-capacity boom-tube rollers; geared-up tape coupled azimuth rotation drive; center-supported pulley shafts; a mechanical, automatically shifting dual-ratio tong-squeeze drive; protected slave-end tapes.

INTERCHANGEABILITY

In general, the Model D is dimensionally interchangeable with a standard Model 8 manipulator with no alteration in mounting arrangement of existing or planned installations. The Model D offers greatly increased reliability and scope in rough-service hot-cell operations with no significant loss of dexterity for performing delicate operations.

COMPARE—THEN SPECIFY CENTRAL RESEARCH MANIPULATORS FOR EVERY NEED





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A simplified guide to select...

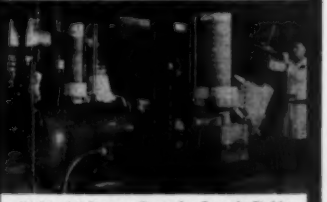
pumps for nuclear fluids!

The chart below offers an easy guide to proven pump types now available for nuclear fluid handling. These pumps are listed by types of fluid circulated in the three basic commercial reactor developments.

	FLUID CIRCULATED	RECOMMENDED PUMPS AVAILABLE	PERFORMANCE RANGES
1	PRESSURIZED WATER, BOILING WATER AND HEAVY WATER	a. Liner Motor Pumps	Capacities: To 17,000 gpm Pressures: To 5300 psi Temperatures: To 700° F.
		b. Mechanically-Sealed Pumps	Capacities: To 125,000 gpm Pressures: To 2,000 psi Temperatures: To 600° F.
2	LIQUID METALS (SODIUM, BISMUTH, ETC.)	a. Vertical-Inert Gas (Mechanically-Sealed)	Capacities: To 25,000 gpm *Pressures: Temperatures: To 1600° F.
		b. Vertical-Oil Filled Motor Pump (Mechanically-Sealed)	Capacities: To 5,000 gpm *Pressures: Temperatures: To 1600° F.
		c. Vertical-Gas Filled Motor Pump	Capacities: To 5,000 gpm *Pressures: Temperatures: To 1600° F.
	*Pressures as required	d. Liner Motor Pumps	Capacities: To 5,000 gpm *Pressures: Temperatures: To 1600° F.
3	ORGANIC	a. Special Process Pumps (Mechanically-Sealed)	Capacities, pressures and temperatures as required.
4	EXPERIMENTAL NUCLEAR DEVELOPMENTS	Byron Jackson's Nuclear Pump Section is ready to assist you in new development projects. All of the above pump types are available and new designs can be created for experimentation.	Capacities, pressures and temperatures as required.

World's Largest Liquid Sodium Pump

ONLY BYRON JACKSON designs and manufactures nuclear pumps and mechanical shaft seals to answer all nuclear fluid handling requirements. BJ Pumps are in use or on order for almost all major commercial reactor developments in the United States. This broad background in nuclear pumping methods can help you find the best answer to your small or large nuclear pumping requirements... with important savings in time and money.



BJ Special Process Pump for Organic Fluids

BJ SINCE 1872

BYRON JACKSON PUMPS

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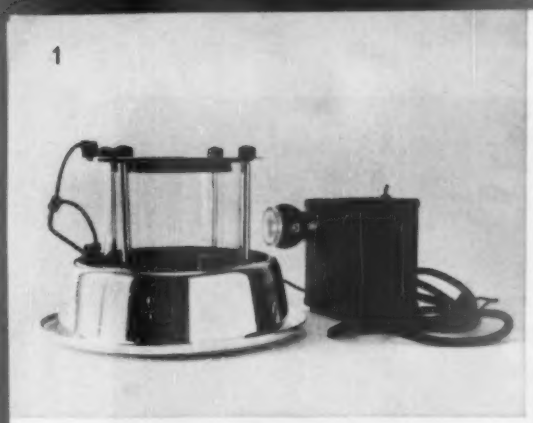
A Subsidiary of Borg-Warner Corporation

BOX 2017A, TERMINAL ANNEX • LOS ANGELES 54, CALIFORNIA

¼ HP, 2000 PSI Liner Motor Pump



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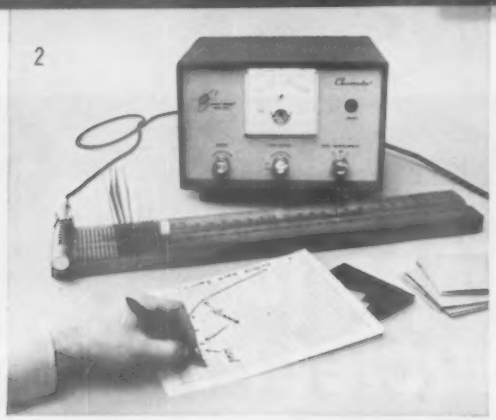

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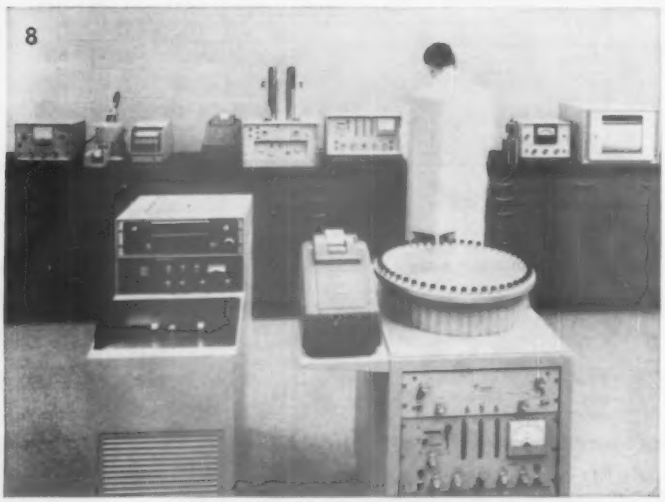

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Photo Courtesy Northeastern University

11

Photo Courtesy Shell Oil Company

How to bring radioisotopes into the science curriculum

Read how these Nuclear-Chicago products help to enlarge the scope of education in the physical and biological sciences

RADIOISOTOPE procedures offer students penetrating insights into the laws of nature. Forward-looking educators are using the equipment illustrated at the left in lectures, for student experiments, and in research. These eleven photographs suggest the scope and completeness of Nuclear-Chicago's instrument line for teaching and research. Systems range from low-cost equipment for demonstration to sophisticated instrumentation for fundamental investigation. All are characterized by reliability, precision, versatility, and inherent safety.

Schools now employing radioisotope techniques will want to consider program expansion to take advantage of the newer products illustrated. Others may well regard the apparatus presented here as a planning guide.

* * *

Low-cost demonstration equipment for the nuclear age became a reality with the introduction of Nuclear-Chicago's Cloudmaster® and Classmaster®. The Cloudmaster (figure 1) is a continuously sensitive cloud chamber that provides a spectacular display of ionization tracks caused by alpha, beta, gamma, and meson radiation. The Classmaster (figure 2) is a complete system for demonstrating radiation absorption, scattering, geometry effects, coincidence loss, etc. In addition, it permits simple tracer experiments using license-exempt radioisotopes. Both instruments enjoy wide acceptance because of their simplicity of operation and the vivid, easily-understood presentations they make possible.

Thirty-three student experiments are contained in a new 187-page experiment manual and 60-page companion volume of instructor notes (figure 3) developed by Nuclear-Chicago under contract with the Atomic Energy Commission. Model 4001 nuclear training system (figure 4) is offered with isotopes, sample preparation equipment, and instruments to perform all the experiments covered in the manual. The system features ease of sample preparation using the chimney funnel shown in figure 5.

Model 4001 is supplied with the long-lived radionuclide set RNS-110 (figure 6) and the radionuclide certificate book RCB-1 (figure 7) with which the instructor can order short- or long-lived isotopes as they are needed. Neither requires an AEC license to purchase or use, and both are available individually.

As student mastery of radioisotope procedures advances, department heads will next want to consider establishing a complete nuclear laboratory for precision handling, detection, and counting of beta- and gamma-emitting isotopes. Such a facility has valuable application to studies in biology, chemistry, physics, and biochemistry at both the graduate and undergraduate levels. A typical installation is pictured in figure 8. In the left foreground is the Model 701 liquid scintillation detector with Logic scaler, and at the right is the Model C120 automatic sample changer for gamma-emitting liquids or solids in test tubes. In the background. from the left, are the Actigraph II® system for scanning radiochromatograms, a low-background automatic sample changer for solid beta samples, and the Dynacon® electrometer for high-efficiency measurement of beta samples in the gaseous phase.

At this stage, the ideally equipped university will lack only the means to create its own radioactive isotopes and to study reactor techniques and fundamental nuclear properties. For these basic needs, Nuclear-Chicago offers a three-step program.

First, undergraduate departments will choose the NH3 neutron howitzer (figure 9) for experiments with low-level neutron sources, production of short-lived, low-intensity radioisotopic tracers, and low-flux activation analysis.

Second, the science and engineering faculties will often cooperate in establishing an advanced training facility centered on the inherently safe Model 9000 subcritical assembly (figure 10). Characteristics of this water-moderated, natural uranium assembly are nearly identical in nature to those of a full-scale power or research reactor, and the student readily masters the fundamentals of reactor theory and design.

Finally, the long-felt need of university research scientists for a versatile, relatively inexpensive, high-intensity neutron source can be well satisfied by the TNC neutron generator designed and manufactured by Nuclear-Chicago's subsidiary, Texas Nuclear Corporation (figure 11). Providing a controllable yield of 4×10^{10} neutrons per second and a thermal neutron flux of greater than 10^8 using an appropriate moderator, the generator is widely employed in activation analysis, process control, applied research and development, and fundamental investigation.

You may request comprehensive data simply by indicating your interests on the coupon below.

nuclear-chicago CORPORATION

Nuclear-Chicago Corporation 345 E. Howard Ave. Des Plaines, Illinois

Please send me literature as checked below:

- ☐ General Catalog S
- ☐ Radiochemistry Experimental Manual
- ☐ Cloudmaster Cloud Chamber
- ☐ Classmaster Demonstration System
- ☐ Model 4001 Nuclear Training System
- ☐ Radionuclide Sources
- ☐ Liquid Scintillation Detectors
- ☐ Automatic Gamma Sample Changers
- ☐ Actigraph II Scanning System
- ☐ Automatic Beta Sample Changers
- ☐ Dynacon Electrometer
- ☐ Model NH3 Neutron Howitzer
- ☐ Model 9000 Subcritical Assembly
- ☐ TNC Neutron Generator

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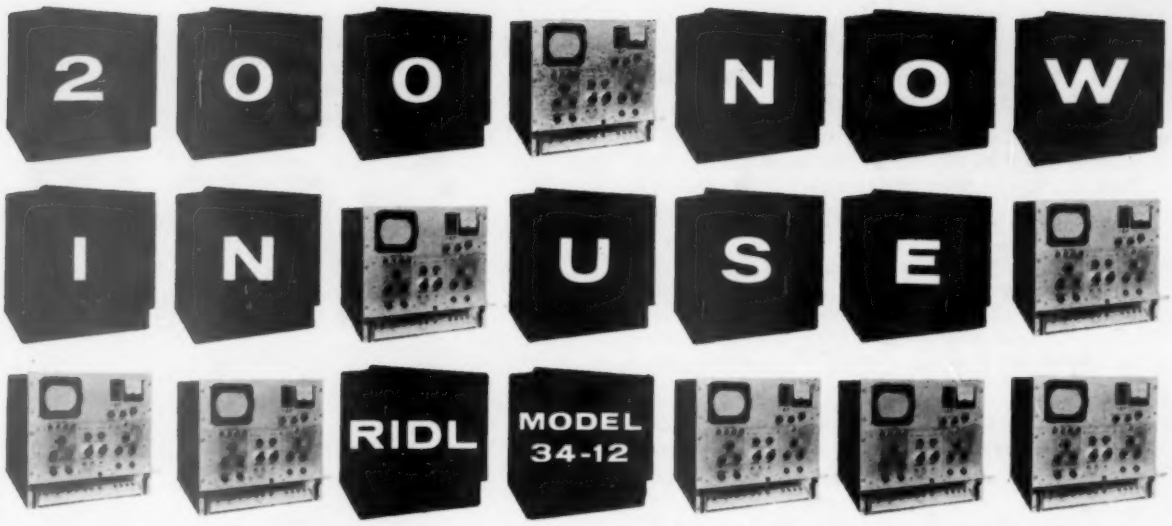

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See this analyzer at the Atomfair in Chicago—Booth number 308-309.

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BREAKTHR

AT ATOMFAIR—Complete model and detailed information on PTR and AMF Atomics' complete range of auxiliary nuclear equipment. AMF ATOMICS Booths 317-320.

Removal of existing core, installation and critical testing of PTR core at IRL took just 6 days.

OUCH!

PTR is the first, new reactor core operated at an existing installation: IRL, Plainsboro, N. J.

ON JULY 7, 1961, AMF ATOMICS' PRESSURE TUBE REACTOR UNDERWENT SUCCESSFUL CRITICAL TESTING. USING FUEL ELEMENTS SEPARATELY ENCLOSED IN THEIR OWN PRESSURE VESSELS, THIS POOL REACTOR CAN ACHIEVE UP TO 40 MW POWER AT FAR LESS THAN HALF THE COST OF ANY PRESENTLY KNOWN DESIGN.

Since the first pool reactor built at Oak Ridge to operate in the KW range, four major improvements contributing to versatility and power of pool reactors have been made. These culminated in the IRL (Industrial Reactor Laboratories) which attains 5 MW and the 15 MW ASTRA reactor in Austria, both built by AMF Atomics.

- ☐ **experimental facilities were introduced into the core**
- ☐ **forced convection of water permitted MW ratings**
- ☐ **a holdup tank was incorporated in the coolant system (IRL) to reduce water activity**
- ☐ **a layer of demineralized water was introduced to reduce surface activity (ASTRA)**

In an open pool, the coolant cannot be pressurized; nor are coolant flow rates beyond 10,000 gpm practical. Further, coolant activation becomes a problem at the 20 MW level.

Yet, an open pool design has maximum inherent accessibility and versatility.

In PTR, AMF Atomics has **proved** a way of maintaining accessibility and, at the same time, increasing power levels far beyond any presently known design.

PTR: UP TO 40 MW POWER

In the PTR concept, coolant and shielding fluids (water) are in separate systems, the former pressurized and flowing through individually encapsulated elements, the latter in a separate pool water loop that cools control blades and also provides a built-in mechanism to collect leakage from the pressurized coolant system should it occur.

In addition to a unique arrangement in the core, PTR fuel elements differ markedly from standard. Tops of elements are sealed. Two-pass coolant flow is utilized in each element: coolant goes up through outside pass of each element, reverses and descends through the inner pass, all, of course, inside the element's pressure vessel. Thus, coolant flow rate is reduced.

OTHER ADVANTAGES OF PTR

PTR's prime advantage is power plus core accessibility at low cost. Here are others:

1. **Existing pool reactors can be converted with minimum coolant system modifications. Two-pass flow reduces capital cost of new coolant system.**
2. **Fast flux irradiation space is provided in center of each element. Coolant temperature can be monitored element by element.**
3. **Geometry of PTR fuel makes core adaptable for in-pile loops.**
4. **Existing fuel element design is used.**
5. **Design avoids expensive reactor pressure vessels.**

There are many other advantages, all equally significant.

AMF ATOMICS A Division of
American Machine and Foundry Company
140 Greenwich Ave., Greenwich, Connecticut

EXPERIENCE, PERFORMANCE...ACROSS THE BOARD, ACROSS THE WORLD

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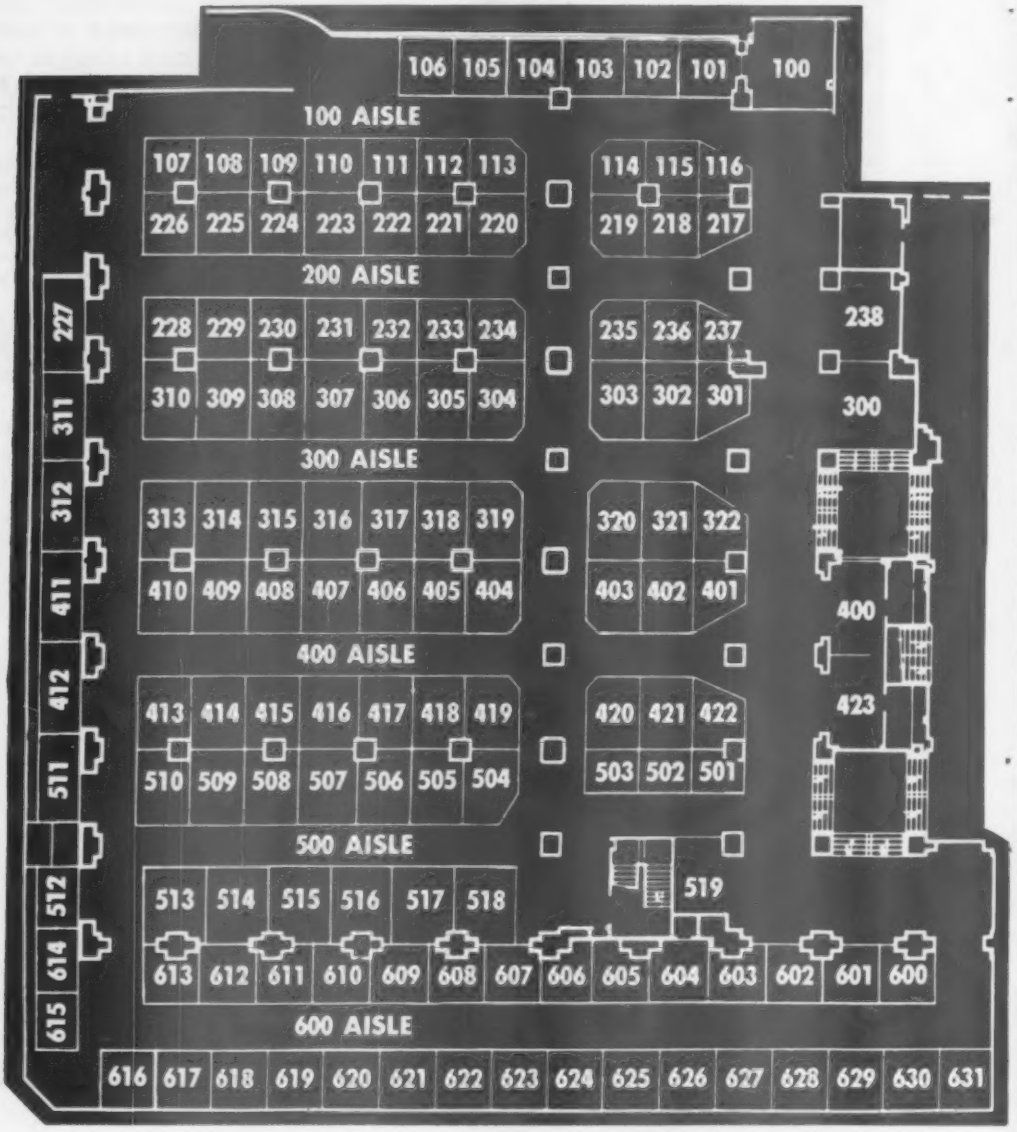

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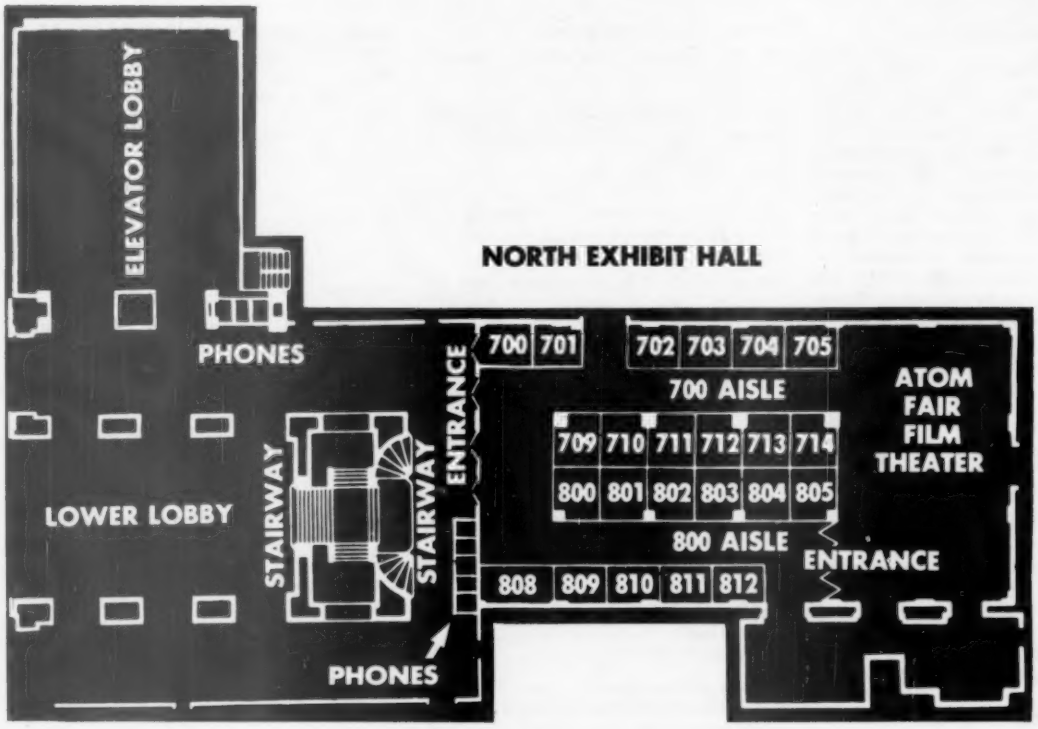

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809	Lerma Engineering Corp.
810	Land-Air, Inc., Instrument & Electronics Div.
811-812	Huntington Alloy Products, Div. of International Nickel Co., Inc.

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Aerojet-General Nucleonics 515, 516
San Ramon, Calif.

Reactor development: space power (SPUR), mobile ground power (ML-1), pulsed (OPERA) and chemical production (hydrazine); fuel manufacturing: beryllia (BEO-UO_2), extruded graphite (4,500°F uranium graphite); materials research: boiling rubidium, cesium, mercury pumped loops, high-temperature corrosion and radiation-tolerant alloys; nuclear equipment: nuclear-electronic NDT scanning systems (GIGI, PICS); test equipment (in-pile multiple-sample creep measurement); nuclear instruments and controls.

See advertisement in this program, Page SS

Aeroquip Corp. 221
Marman Div.
11214 Expositions Blvd.
Los Angeles 64, Calif.

Standard and custom-designed joints, clamps, couplings, flanges, bellows and duct assemblies for extreme operating requirements; mechanical hardware for tubes and pipes.

Allis-Chalmers Manufacturing Co. 228–230
P. O. Box 512
Milwaukee 1, Wis.

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American Association for the Advancement of Science 233
11 W. 42nd St.
New York 36, N. Y.

Publishes weekly magazine, Science.

AMF Atomics 316–319
Division of American Machine and Foundry Co.
140 Greenwich Ave.
Greenwich, Conn.

Remote handling devices and reactors.

See advertisement in this program, Pages X, Z, AA

Atomic Energy of Canada Ltd. 115, 116
Commercial Products Div.
P. O. Box 93
Ottawa, Ontario, Canada

Gammacell 200 Co^{60} irradiator, Co^{60} sources; neutron sources, radioisotopes.

See advertisement in this program, Page W

Atomics International 313–315
Division of North American Aviation, Inc.
8900 DeSoto Ave.
Canoga Park, Calif.

Manufacturer of organic-cooled and sodium-cooled power reactors and solution-type research reactors.

See advertisement in this program, Page XX

Atomics, Physics & Science Fund, Inc. 224
1033 30th St., NW
Washington 7, D. C.

Fund invests in science with emphasis on atomics and physics. Prospectus is free at the booth. For teaching science and for advertising, Fund will distribute free copies of its "Periodic Chart of the Atom," and "The Spectra of Modern Science."

The Babcock & Wilcox Co. 607–609
161 E. 42nd St.
New York 17, N. Y.

Activities will be shown in areas of production of complete power, propulsion and research reactors, development of experimental units and fabrication of component parts and fuel elements.

See advertisement in this program, Page ZZ

Baird-Atomic, Inc. 618, 619
33 University Rd.
Cambridge 38, Mass.

Counting instruments, pulse-height analyzers and detectors, in addition to products of Atomic Accessories, Inc., Sharp Laboratories, Inc. General Measurements, Inc. and Controls for Radiation, Inc.

See advertisement in this program, Page K and PP

S. Blickman, Inc. 412
536 Gregory Ave.
Weehawken, N. J.

Stainless-steel vacuum dry boxes for controlled-atmosphere work. Literature on 22 different types of safety enclosures and custom fabrication of complex and unusual equipment.

Borg-Warner Corp. 231, 232
200 South Michigan Ave.
Chicago, Ill.

(See Byron Jackson Div. and Marvel-Schebler Products Div.)

Brush Beryllium Co. 504, 505
5209 Euclid Ave.
Cleveland 3, O.

Beryllium-metal and beryllium-oxide components in various forms and shapes associated with nuclear applications.

Byron Jackson Div. 231, 232
Borg-Warner Corp.
P. O. Box 2017 Terminal Annex
Los Angeles 54, Calif.

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See advertisement in this program, Page U

Cambridge Filter Corp. 400
P. O. Box 1255
Syracuse 1, N. Y.

High-efficiency air filters for removing radioactive and toxic dusts; accessory items for laboratory, manufacturing and reactor facilities.

See advertisement in this program, Page KK

Central Research Laboratories, Inc. 236, 237, 301, 302
Red Wing, Minn.

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See advertisement in this program, Page T

Charleston Rubber Co. 404
Stark Industrial Park
Charleston, S. C.

Specially compounded milled Neoprene dry-box gloves, radiation-shielding Rad-Bar dry-box gloves, Neo-Sol "Sensi-Touch" gloves.

Combustion Engineering, Inc. 405, 406
Windsor, Conn.

Manufacturer of core components, designer of reactor systems for test and research,

services for various nuclear applications, design and fabrication of steam-generating equipment.

Commonwealth of Kentucky 110
Dept. of Economic Development
Frankfort, Kentucky

State licensing and regulatory program for nuclear-materials manufacturers and users, transportation and wage-rate data, labor availability, industrial sites, financing plans, topographic and geologic maps and miscellaneous research services.

See advertisement in this program, Page PP

Corning Glass Works 310
Corning, N. Y.

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Eberline Instrument Corp. 300
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Santa Fe, N. M.

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Edlow Lead Co. 419
729 Bank St.
Columbus 6, O.

Samples of lead castings with nuclear applications, isotope shipping containers, containers for disposal of radioactive waste, components for instrumentation.

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Tallahassee, Fla.

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General Atomics 103–106
Div. of General Dynamics Corp.
P. O. Box 608
San Diego 12, Calif.

Displays on High-Temperature Gas-cooled Reactors for electric power generation; beryllium-oxide moderated gas-cooled reactors for ship propulsion and other applications; TRIGA reactors for research, training, isotope production and controlled pulsed operation; direct conversion of heat to electricity; controlled-thermonuclear reactions; nuclear power for space vehicles; and other programs.

See advertisement in this program, Page NN

General Electric Co. 320–322, 401–403
Atomic Power Equipment Dept.
San Jose, Calif.

Boiling-water reactor tower plants, BWR plant-construction progress, nuclear fuel, nuclear-electronic products including reactor-control and safety systems, area radiation, monitoring systems, ionization chambers, electronic components, complete irradiation services, isotopes, research and development studies.

General Mills Electronics Group 513, 514
Automatic Handling Equipment Dept.
419 N. Fifth St.
Minneapolis 1, Minn.

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Massillon, O.

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Hamner Electronics Co., Inc. 238
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Princeton, N. J.

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Cleveland 6, O.

Complete line of scintillation and optical crystals. NaI(Tl) crystals are sold in standard, matched-window, and integral-line (crystal-phototube) assemblies. **Scintillation Phosphor Brochure** describes CsI(Tl), LiI(Eu), Li^6I(Eu), anthracene, plastics, Cerenkov detectors. Physicists available for detector design. Optical Crystals for infrared, ultraviolet (to Lyman α), LASER crystals, windows, monochromators.

See advertisement in this program, Page J

High Voltage Engineering Corp. 100
S. Bedford St.
Burlington, Mass.

Van de Graaff and Microwave Linear Accelerators for electron-beam processing, radiation research and neutron activation. New electromagnetic isotope separator and positive-ion and electron irradiation-service facilities discussed.

Hughes Aircraft Co. 600–602
Florence & Teale Sts.
Culver City, Calif.

Mobot Mark III, model of Mono-Pulse Linac, new radiation-detection packages, photos and description of cyclotron.

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Div. International Nickel Co., Inc.
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Producers of nickel alloys for nuclear, corrosive, and high-temperature applications. Alloys include MONEL nickel-copper alloys, INCOLOY nickel-iron chromium alloys. Also a complete line of welding products for joining these alloys, as well as for joining cast irons and dissimilar alloy combinations.

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Chicago, Ill.

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International Publications, Inc. 312
801 Third Ave.
New York 22, N. Y.

Atomic-energy publications of the Atomic Industrial Forum and International Atomic Energy Agency.

See advertisement in this program, Page FF

Kaman Nuclear 220
P. O. Box 3217 N. End Station
Colorado Springs, Colo.

Neutron generators for activation analysis, reactor optimization, classroom demonstration, oil-well logging and space applications. Included is new model of low-cost generator especially designed for industrial-lab and plant-stream applications. Services include study and experimental contracts in nuclear physics.

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S. Center St.
Adrian, Mich.

Chemical preparation bench, counting-bench assembly with instrumentation and a glove box for working with radioisotopes.

SENTRON

3-S

The SENTRON is a completely automatic self-testing gamma radiation alarm system. Self test provides positive (visual and audible) indication of any system failure.

The SENTRON provides continuous linear readout of all channels. Alarm response is less than ½ seconds. Operation is jam and transient proof.

System requires no calibration, and construction is for low cost flexibility. For more information contact:

NUCLEAR MATERIALS AND EQUIPMENT CORPORATION

NUMEC

APOLLO, PA.

TWX [illegible] PHONE GR 7-9511 CABLE NUMEC

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23–15 Borden Ave.
Long Island City 1, N. Y.

"INSMETALS" and equipment to prevent escape of radiation. This includes shielding for nuclear ships, transportation of spent fuel, commercial power-reactor shielding, radar and personnel shields, waste disposal, insect and plant irradiators, student-training irradiators, medical-therapy equipment, hot-laboratory facilities, lead bricks and extrusions, "Raysist" putty, etc. Company also serves as consultants on all shielding problems.

Kollmorgen Corp. 218
347 King St.
Northampton, Mass.

Modular Periscope, Model 301 Hot-Cell Periscope, remote-viewing instrument.

See advertisement in this program, Page QQ

Land-Air, Inc. 810
Instrument and Electronics Div.
440 Hester St.
San Leandro, Calif.

Portable and bench models of radiation-monitoring instrumentation for scintillation, geiger or proportional probes, turret-crystal detector for reactor-area monitoring for gammas and fast and thermal neutrons, high-voltage power supply for nuclear-counting equipment, portable radioactive-gas monitor, and probes and other accessories.

See advertisement in this program, Page VV

The Landsverk Electrometer Co. 606
641 Sonora Ave.
Glendale 1, Calif.

Dosimeters, Roentgenmeters, isotope-analysis units, military radiacmeters, Civil Defense instruments.

See advertisement in this program, Page R

Lerma Engineering Corp. 809
53 Clark Ave.
Northampton, Mass.

Periscopes, borescopes and other remote-viewing optical instruments for underwater inspection, hot cells and observation of refueling operations. Periscopes built in lengths to 40 ft or longer with variable powers, scanning and fields up to 180°F. Illuminated borescopes based on the Omniscope design with interchangeable high-power angle heads.

Lionel Electronic Laboratories, Inc. 234
1226 Flushing Ave.
Brooklyn 37, N. Y.

Radiation equipment, portable survey meters, air-particle monitors, doorway monitors, alpha-beta-gamma detectors, neutron detectors and special medical detectors for eye, brain and stomach, as well as custom-made detectors for outer space.

See advertisement in this program, Page LL

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the **INTERNATIONAL ATOMIC ENERGY AGENCY**

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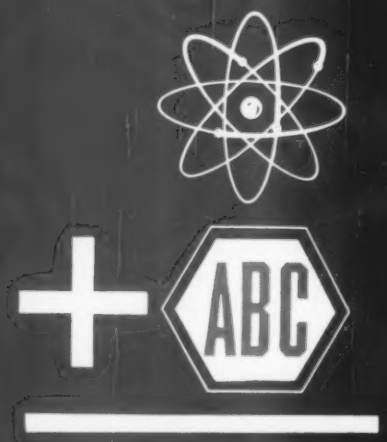


2 symbols of power!

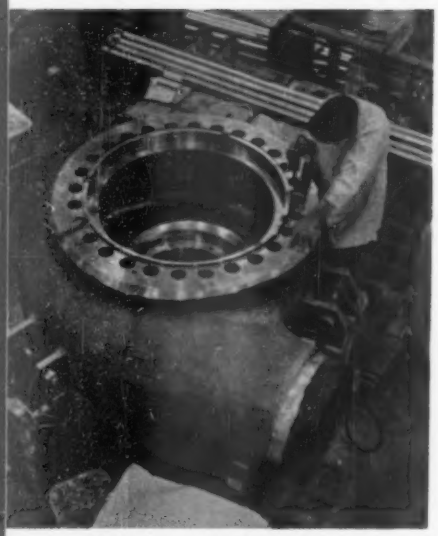
The ABC symbol carried by this publication and the atom both signify power. Professionally the subscribers to this publication exert power over the elemental particles of nature. As *paid* subscribers to this Audit Bureau of Circulations publication, they also exert direct power over its editorial content – for, in order to *earn* subscription dollars, an ABC-audited publication must be constantly aware of its final "board of editors," its subscribers. This reader influence maintains editorial quality at its peak and assures advertisers better than any other circulation system that the readers they reach under the ABC symbol are actively interested in this ABC-audited publication – and others.

NUCLEONICS

A McGRAW-HILL PUBLICATION / 330 WEST 42ND STREET, NEW YORK 36, NEW YORK

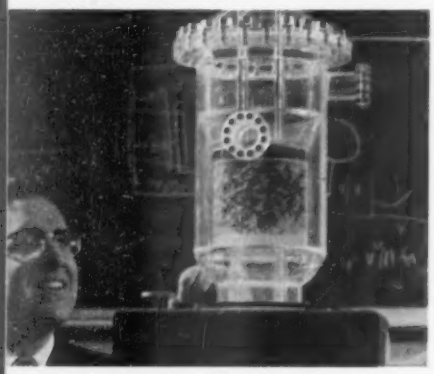
Thousands of Westinghouse people work full time on commercial atomic power

People, facilities and successful experience . . . these are reasons why Westinghouse is the world's leading supplier of nuclear power plants and components.



Westinghouse Quality Control inspector is working on a nine ton stainless steel pump casing at the Atomic Equipment Department in Cheswick, Pa. Department produces canned motor pumps, valves and control rod mechanisms.

Electron Beam Welding of core components is one of the many special skills employed at the Atomic Fuel Department, Cheswick, Pa. Standard products of the department are reactor cores and their components.



Dr. James H. Wright, shown here with an organic moderated fluidized bed reactor model, is also doing important development work on the concept of an integral boiling and superheat reactor (IBSHR).

Westinghouse Engineers, after design, follow through on construction of reactor plants such as this 5,000 kilowatt plant being built at Saxton, Pa., for the Saxton Nuclear Experimental Corp. This new reactor will be used with an existing turbine generator at the Pennsylvania Electric Company site.

Critical Experiment Station at Testing Reactor. This technician is working in the low power test facility used to confirm physics calculations by experiments before exposure in the reactor.

Westinghouse Testing Reactor facility includes hot cells and metallographic cells for post-irradiation examination of samples. Nuclear fuels and other materials can be tested inside cylindrical fuel elements of reactor core. Chemical, analytical and counting laboratories are used for post-irradiation tests.

JI-59503RI

Westinghouse Mathematicians are working out the solution to a nuclear fuel problem at this computer installation in the Atomic Power Department at Forest Hills, Pa.

Dr. W. E. Shoupp, Technical Director of the Atomic Power Department, plays vital role in developing atomic fueled plants to the point where they will be economically competitive with fossil fueled plants in the generation of electric power.

Skilled Machinist is working on the shell and flange for a canned motor pump on a 100" vertical boring mill at the Atomic Equipment Department.

Dr. Joseph C. Danko heads up promising advanced research of the thermoelectric reactor, a potential means of generating electricity directly from fission heat without a turbine-generator unit.

Fuel Assembly Operation at the Atomic Power Department, where facilities are maintained for development of advanced fuel concepts. Technician is working on cage of a fuel assembly.

Dr. Sidney Krasik, Technical Director of Astronuclear Laboratory, works on applications of atomic power in outer space, such as nuclear power propulsion, the nuclear ram jet and auxiliary power plants for space vehicles.

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Westinghouse

Westinghouse Electric Corporation
Box 868, Pittsburgh 30, Pa.

Republic Aviation.

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It is the act of going directly to the most concentrated source of supply to find 'the right man' for the job.

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Write for the new 52-page booklet ***"Recruiting Engineers"***
Address: David Hawksby, Classified Advertising Division, Nucleonics, Post Office Box 12, New York 36, N. Y.

The engineers you need are the engineers who read

NUCLEONICS

A McGRAW HILL PUBLICATION
CLASSIFIED ADVERTISING DIVISION
POST OFFICE BOX 12 NEW YORK 36, NEW YORK

Lockheed Aircraft Corp. 414
Lockheed Nuclear Products
1500 Northside Drive N. W.
Atlanta 18, Ga.

Nuclear instrumentation with transistors, including nonoverloading amplifier, preamplifier, scaler, area monitor, pulse-height analyzer, fast-neutron survey meter, digital volt meter and detection components.

The Marquardt Corp. 616, 617
16555 Saticoy St.
Van Nuys, Calif.

Direct-cycle diphenyl reactor system for power generation and process-heat applications are compared with conventional steam plants; corporate capabilities in advanced power systems, controls, rocketry and electronics.

Marvel-Schebler Products Div. 231, 232
Borg-Warner Corp.
2195 South Elwin Rd.
Decatur, Ill.

Designers and manufacturers of control-rod drive mechanisms, electronic-control systems, valves and installation tooling for reactors. Services also include functional testing for design environments and rejuvenation of users equipment.
(Also see Byron Jackson Div., Borg-Warner Corp. and Borg-Warner Corp.)

Metals & Controls Inc. 225, 226
Div. of Texas Instruments Inc.
34 Forest St.
Attleboro, Mass.

Work for Pathfinder reactor fuel elements. Demonstration of 100% NDT test on zircaloy tubing.

See advertisement in this program, Page O

Minneapolis-Honeywell Regulator Co. 603, 604
Wayne and Windrim Ave.
Philadelphia 44, Pa.

Nuclear instrumentation and controls.

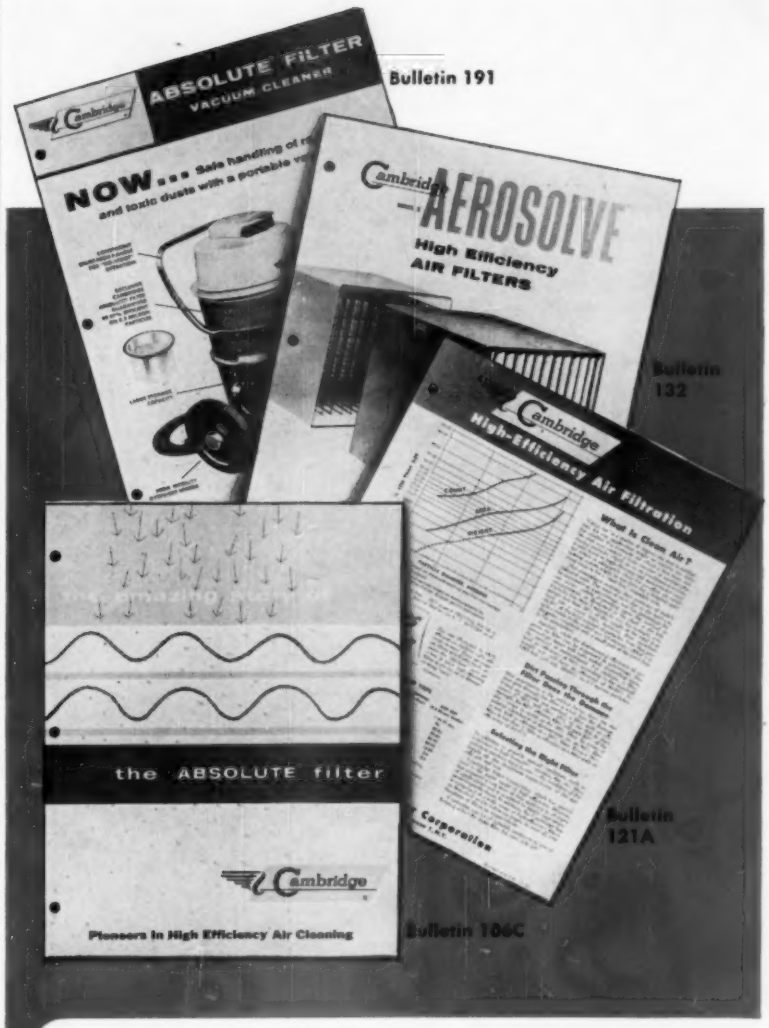
Minnesota Mining and Manufacturing Co. 614
900 Bush Ave.
St. Paul 6, Minn.

Two major product lines—one in reactor fuels and components and the other in radioactive products: self-luminous, industrial and medical radiation sources. Both product lines make extensive use of the microspheres developed by 3M research for greater strength, safety and flexibility of application.

See advertisement in this program, Page L

National Carbon Co. 506, 507
Division of Union Carbide Corp.
270 Park Ave.
New York 17, N. Y.

Low-permeability graphite to clad fuel elements for gas-cooled reactors. Also on display are other forms of nuclear-grade



Here Is Air Cleaning KNOW-HOW!

and you can have it... FREE!

When you are dealing with air that contains radioactive or toxic dusts, you don't dare guess. The cleaning method must be POSITIVE. Specific filter selection must be determined by the nature and concentration of the contaminants.

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LIONEL ELECTRONIC LABORATORIES

Formerly Anton Electronic Laboratories, Inc.

1226 FLUSHING AVE., B'KLYN 37, N. Y.

A DIVISION OF THE LIONEL CORPORATION

graphite for use as moderators, reflectors, thermal columns, shields, molds and crucibles. Pyrolytic carbon-coated uranium-dicarbide particles and uranium-bearing graphite fuel elements in the form of tubes, spheres and rods also shown.

See advertisement in this program, Page P

National Lead Co. **709, 710, 800, 801**
111 Broadway
New York 6, N. Y.

Gamma shielding materials—from stock or made-to-customers' specifications. Fully fabricated shielding, including steel cladding and accessory equipment; shipping and storage casks; depleted-uranium shielding; design and engineering services; nuclear fuel elements of UO_2; carbide; fuel-element materials; thorium castings; uranium scrap processing; spent-fuel element transportation and reprocessing services.

See advertisement in this program, Page TT

Nuclear-Chicago Corp. **629–631**
333 Howard Ave.
Des Plaines, Ill.

Medical, biological, research, training and industrial nuclear instrumentation and systems; TNC neutron generator and industrial instruments for continuous measurement and control of moisture and density.

See advertisement in this program, Page V

Nuclear Corporation of America **517**
Instrument and Control Div.
2 Richwood Pl.
Denville, N. J.

Health-physics and nuclear-counting equipment such as portable fast-neutron dosimeters, military GM monitors from 0.5 mr/hr to 500 r/hr, ion-chamber survey meters, transistor count-rate meters, scintillation counters and scalers. Shown also is a urinalysis kit for tritium environments. Scientific staff is available for custom-built instruments and detectors.

Nuclear Data, Inc. **627, 628**
3833 W. Beltline
Madison, Wis.

Model ND-130A computer analyzer with internal data reduction including integration.

See advertisement in this program, Page S

Nuclear Industries, Inc. **307**
10 Holland Court
Valley Stream, N. Y.

Complete line of fully-transistor educational and research nuclear instrumentation including the Cosmic Double Delay Line clipped linear amplifier, the Cosmic Multi-Coincidence Unit, several novel survey instruments, Flexo-Rabbit Pneumatic Transfer System, low-level scintillation detector, VisiFlux Neutron Howitzer with numerous foils, and the latest REAC analytical scaler and well.

Nuclear Materials and Equipment Corp. **808**
Warren Ave.
Appollo, Pa.

Nuclear equipment displayed will be Densitron—a density-measuring device for mass-produced specimens—electronic weight-deviation balance, cathodic vacuum etcher, vacuum evaporator, Sentron, area-monitoring system, personal radiation monitor, variety of nuclear fuel materials (coated particles and ceramic shapes), hafnium crystal bar —largest ever grown.

See advertisement in this program, Page FF and MM

Nuclear Measurements Corp. **227**
2460 N. Arlington Ave.
Indianapolis 18, Ind.

Instrumentation for reactors, hot cells, linear accelerators and other laboratory facilities.

See advertisement in this program, Page OO

Oak Ridge National Laboratory **512**
(Union Carbide Nuclear Company)
P. O. Box X
Oak Ridge, Tenn.

Principal supplier of bulk stable and radioisotopes. Nearly 250 stable isotopes of ~60 different elements and more than 100 different radioisotopes are routinely inventoried; fission products such as Cs^{137}, Sr^{90}, Ce^{144} and Pm^{147} provided in kilocurie amounts; encapsulated radioisotope sources available; supported and unsupported targets of many enriched stable isotopes fabricated.

Oak Ridge Technical Enterprises Co. (ORTEC) **109**
140 E. Division Rd.
Oak Ridge, Tenn.

Solid-state detectors, amplifier systems, ion sources and associated terminal electronics.

Packard Instrument Co., Inc. **112, 113**
Box 428
La Grange, Ill.

Instruments for measuring radioactivity including Tri-Carb Liquid Scintillation Spectrometer. Also Auto-Gamma Spectrometer System, fuel-element analyzer for nondestructive testing of nuclear fuel elements and a new scintillation counter that can be used as a whole-body counter for small animals or as an arm counter for humans.

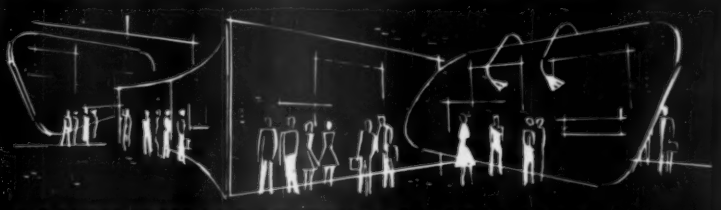
See advertisement in this program, Page RR

Penberthy Instruments Co., Inc. **613**
6701 Maynard Ave.
Seattle 8, Wash.

Radiation shielding windows and glasses including a special neutron-absorbing glass, nondarkening glass tubing, infrared transmitting glasses, radiation dosimeters, bullet- and explosion-resistant windows and other special glasses.

VISIT NUMEC'S DISPLAY

NORTH HALL
BOOTH 808



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- Radioisotope Sources
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- Complete Instrumental and Classical Chemical Services

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- SENTRON—Area Radiation Monitoring Systems
- PRM—Personal Radiation Monitors
- DENSITRON—Automatic Density Inspection Instrument
- Weight Deviation Balances
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- Glove Box Installations
- Booth-Cromer Gages
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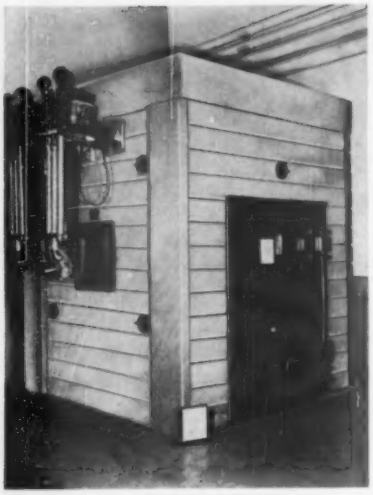

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An economical, convenient answer to the need for a light to medium duty hot cell is provided by the **RAY PROOF HOT CELL.** Complete in every detail, unit is sold on an installed basis. The customer need only provide a suitable level location and a discharge duct for the self-contained 250 cfm filter-ventilating system.

RAY PROOF designs and manufactures materials and devices for shielding against X-Ray, Gamma Ray, Neutrons and RF interference: Such as Shielded Doors, Windows, Rooms, Production Cabinets, Shielding Devices, High Density Concrete Blocks, Containers, Cells, Safes, Screens, Portable Shielded Enclosures, Hot Cell Shielding Components and Fume Hoods.

Request Our New Nuclear Shielding Catalog

Visit us at ATOMFAIR Booth #223

RAY PROOF

RAY PROOF CORP.
STAMFORD, CONNECTICUT

Pergamon Press, Inc. 511
122 E. 55th St.
New York 22, N. Y.

Publishers of books in field of nuclear energy and related areas; journal of **Health Physics**, journal of **Inorganic and Nuclear Chemistry**, journal of **Infra-Red Physics**, journal of **Nuclear Energy** and similar publications.

Permali Inc. 610
Bridgeport St. Extension
Mt. Pleasant, Pa.

Neutron shielding made from wood veneers and synthetic resins, fully synthetic resins impregnated and used where high-dimensional stability is required, resins uniformly loaded with 3% by weight of boron but less stable dimensionally.

Pittsburgh Plate Glass Co. 413
1 Gateway Center
Pittsburgh 22, Pa.

Nuclear shielding windows, component and related materials.

Radiation Counter Laboratories, Inc. 611, 612
5121 W. Grove St.
Skokie, Ill.

Two transistor multichannel analyzers; a set of transistor laboratory radiation instruments; a neutron activator; miscellaneous scalers and monitoring instruments.

See advertisement in this program, Page E

Radiation Instrument Development Laboratory, Inc. 308, 309
61 E. North Ave.
Northlake, Ill.

New line of small instruments with transistors covering scaler and spectrometer systems, ratemeters and various counters. RIDL 400-Channel Pulse-Height Analyzer with magnetic tape read-out, multiple-detector input and choice of other read-out devices will be featured. Star of the RIDL show will be the Model 34-13 space-going 32-channel Pulse-Height Analyzer. Choice instruments from the RIDL vacuum-tube line will complete the exhibit.

See advertisement in this program, Page Y

Ray-Proof Corp. 223
843 Canal St.
Stamford, Conn.

Nuclear-shielding products and materials including prefabricated hot cells, high-density concrete products and hot-lab accessories.

See advertisement in this program, Page NN

Research Equipment Co. 107
502 Sunnyside Ave.
Wheaton, Ill.

Shielding windows, remote-positioning devices, filter-change equipment, light fixtures for hot cells, periscopes, remote pipettes.

General Atomic Provides

PULSED RADIATION FACILITIES

An unusual combination of pulsed radiation facilities is now available on a scheduled basis to industry and military organizations for conducting transient radiation effects testing. These facilities include, at a single location, the **TRIGA Mark I** and **Mark-F** reactors and the high-energy **Electron Linear Accelerator.**

In addition to the skilled personnel who operate the facilities, scientific and engineering staff members with extensive experience in transient radiation effects testing programs are available to assist in planning and executing specific research programs.

Testing can range from fundamental studies of transient radiation effects to the environmental testing of specific components and systems. The TRIGA reactors developed by General Atomic are designed to yield reproducible pulses of neutrons and gamma rays up to a peak fast neutron flux of 4.0×10^{16} nv. The powerful 45 Mev L-band Electron Linear Accelerator provides extremely short pulses of high energy electrons, gamma rays or both.

Write now for complete information on these facilities to: Applications Group-AB, General Atomic, P.O. Box 608, San Diego 12, California.

Visit us at the Atomfair Booths 103-106

GENERAL DYNAMICS
GENERAL ATOMIC DIVISION

Reuter-Stokes Electronic Components, Inc. 605
2149 Hamilton Ave.
Cleveland 14, O.

Neutron detectors including proportional counters, fast-neutron detectors, ionization chambers and fission counters/chambers, sapphire metal seals, special attached cables for detection devices and ceramic metal seals.
See advertisement in this program, Page D

Royal Research Corp. 235
Division of Royal Industries, Inc.
11824 Dublin Blvd.
Hayward, Calif.

Enclosures for containing and handling radioactive, toxic or biologically active materials. Included are high-vacuum enclosure, portable vacuum system, inert-gas welding enclosure, series-S gloved dry box and high-temperature gas-chromatography unit. Prime contractor in developing Ce^{137}-fueled thermoelectric generator (model on display) for Office of Isotopes Development, AEC.

Snyder Manufacturing Co., Inc. 217
1458 Fifth St., N. W.
New Philadelphia, O.

Protective clothing and equipment manufactured from vinyls, polyethylenes, paper, lead-loaded materials and textiles; suits, hoods, shoe covers, dry boxes, liners and manipulator sleeves custom fabricated to customer specifications.

Spencer Chemical Co. 219
Dwight Bldg.
Kansas City 6, Mo.

Nuclear fuel materials—ceramic grade UO_2 and other uranium and thorium compounds in all enrichments and quantities.
See advertisement in this program, Page N

Superior Tube Co. 622
P. O. Box 191
Norristown, Pa.

Nuclear fuel-element tubing and heat-exchanger tubing made from stainless steels, nickel alloys and reactive metals. Straight and spiral integral finned tubing for reactor fuel-element cladding applications. Also cross sections of control rods produced from boron stainless, cadium-indium silver and hafnium. Sample sections of zircaloy fuel containers and burnable poison rods.

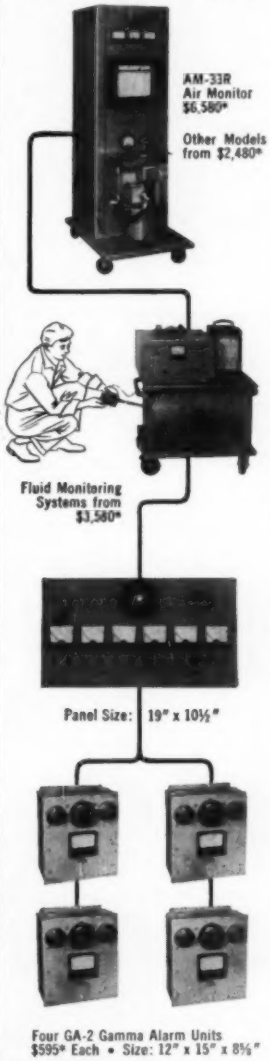
Sylcor 518
Division of Sylvania Electric Products Inc.
Cantiague Rd.
Hicksville, L. I., N. Y.

Research and development of pilot-plant and fuel-poduction facilities for metallic and control rods; custom vacuum and atmosphere metallurgy; unique cladding and brazing techniques and precision fabrication of other nuclear, space and missile components.

Monitoring Systems

DESIGNED, BUILT AND BACKED BY NMC INDIANAPOLIS, INDIANA

What is your radiation monitoring problem? Airborne particulates . . . gaseous or liquid radiation . . . or gamma area radiation? NMC equipment can monitor any one or all with individual units or complete systems. The system shown here presents data at each station and on a control room follow meter panel. It warns of caution and alarm levels; can even operate emergency controls.



AIR MONITORS

NMC air monitors offer many exclusive advantages. For example, Model AM-33R shown here detects and identifies long half-life emitters directly, almost immediately, with one detector. Other monitors require five hours or more for identification, due to the natural radon progeny. The four NMC models are . . .

MODEL	CHANNELS	FILTERS	ACTIVITY DETECTED
AM-2A	1	Fixed	α, $\beta\gamma$ or γ
AM-3A	1	Moving	α, $\beta\gamma$ or γ
AM-22R	3	Fixed	α and $\beta\gamma$ Shows ratio of $\beta\gamma/\alpha$
AM-33R	3	Moving	α and $\beta\gamma$ Shows ratio of $\beta\gamma/\alpha$

FLUID MONITORS

The NMC fluid monitoring system detects radioactivity in gas or water at MAC levels. Used with an NMC air monitor, it measures activity of the gaseous component of the discharge from the air monitor. Contamination and a separate pumping system are eliminated by employing the air pumping system and filter mechanism of the air monitor. The fluid system includes the FMS-1 shield with 30 liter sampling chamber, and two detectors—GM or NaI scintillation—operating in parallel; the LCRM-2M logarithmic count ratemeter with built-in bell and alarm lights; and portable EA graphic recorder.

FOLLOW METER PANELS

Each monitoring station can be connected to a follow meter panel in the central control room with inexpensive unshielded standard electric code wiring. There's a meter for each station to show the radioactivity being detected, and lights to indicate caution and alarm levels. The bell sounds for an alarm condition at any station. Multipoint recorders and remote emergency controls may be connected to the panel.

AREA MONITORS

Each of the four GA-2 units shown here is a complete monitoring station that indicates and reports unusual or excessive gamma radiation. It mounts on the wall and wires to any 110-volt circuit, eliminating the central power supply required by other systems. Each GA-2 has an amber and red light, bell, indicating meter, and complete alarm system. Units readily adapt to a complete system. They connect to follow meters and graphic recorders; are interchangeable without the usual installation matching and calibration. They are not sensitive to temperature, line voltage changes or external electro-magnetic radiation. The amber light is also a fail-save device, signaling component failure. An auxiliary power supply for each GA-2 is available.

**All Prices fob, Indianapolis • For full details, write, wire or phone collect*—LIBERTY 6-2415

Nuclear Measurements Corp.
2460 N. Arlington Avenue • Indianapolis 18, Indiana
International Office: 13 E. 40th Street, New York 16, N.Y.
NMC INDIANAPOLIS

SEE THE KENTUCKY EXHIBIT

Booth 110 at the "Atomic Fair"
Chicago, November 6-9

Technical Associates 222
140 W. Providencia Ave.
Burbank, Calif.

Manufacturers of health-physics monitoring instruments and nuclear-research equipment, hand and shoe monitors, portal monitors, portable survey instruments, automatic sample changers, scintillation detectors, ratemeter, scaler, single-channel spectrometry systems, lead shields and source containers.

Technical Measurement Corp. 407, 408
441 Washington Ave.
North Haven, Conn.

Complete line of multichannel-analyzer equipment including the recently developed Models 404 and 402 400-channel analyzers. Also a variety of analog and digital read-out equipment to be used with TMC analyzer systems.

See advertisement in this program, Page WW

Teleflex Inc. 409, 410
Church Rd.
N. Wales, Pa.

Reactor-flux mapping systems, control-rod drives, source drives, fuel-loading mechanisms, ion-chamber drives, sample-irradiation drives, a group of radiation-resistant high-temperature coatings for reactor applications providing corrosion protection or lubrication. Teleflex provides U. S. coverage for Avro Industries of Canada.

See advertisement in this program, Page YY

Turco Products, Inc. 411
24600 S. Main St.
Wilmington, Calif.

Radioactive decontamination compounds and equipment consisting of ultrasonic cleaning unit, a dual-jet washer for mechanically cleaning tank interiors; a Turco Steamerette that uses plant steam supply for steam cleaning and Dy-Chek, the dye penetrant method of flaw location in metals.

United Nuclear Corp. 417, 418
5 New St.
White Plains, N. Y.

Products ranging from nuclear-fuel materials to special purpose reactors. Also graphic presentation of over 450,000 ft² of facilities used in performance of research, design, development and production assignment. Qualified personnel will answer enquires and describe in detail products and capabilities offered.

See advertisement in this program, Page F

U. S. Atomic Energy Commission 620, 621
Office of Technical Information
Washington 25, D. C.

Technical information activities of the AEC.

U. S. Department of Commerce 623, 624
Office of Technical Services
Washington 25, D. C.

Technical information service of the Department of Commerce.

United States Steel Corp. 304–306
525 William Penn Pl.
Pittsburgh 30, Pa.

Alloy steels, stainless steels, steel forgings, structural steels, stainless-steel tubing; engineering and fabrication services of Consolidated Western Steel Division.

Victoreen Instrument Co. 508–510
5806 Hough Ave.
Cleveland 13, O.

Transistor 200-, 400- and 800-channel analyzers, multidimensional analyzers; count-rate meters, scalers, linear amplifiers, single-channel analyzers, high-voltage supplies, vibrating-reed electrometers, micro-microammeters, radiation-monitoring systems (gas, particulate, liquid, area), dosimeters, survey meters, precise-dose and dose-rate measuring instruments, design and calibration services.

Westinghouse Electric Corp. 420–422, 501–503
3 Gateway Center
Pittsburgh 30, Pa.

Nuclear fuel, pumps, model of Westinghouse test reactor and neutron-detector tubes. Information on Atomic Power Department's facilities for design, construction and complete fuel servicing.

See advertisement in this program, Page GG

NEW!

FAST NEUTRON and GAMMA DOSIMETRIC SYSTEM

by Bendix

Measures fast neutrons and gamma (or x-ray) dose in rads.

Consists of two direct-reading pocket dosimeters. One is tissue-equivalent for fast neutron and gamma dose. The other is neutron-insensitive for gamma dose only. Range is 200 millirads full scale (ranges to 2000R available.)

Write for Bulletin NDS

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6 x	8°	H_2O 3 ft. Air 27 in. to infinity	4mm
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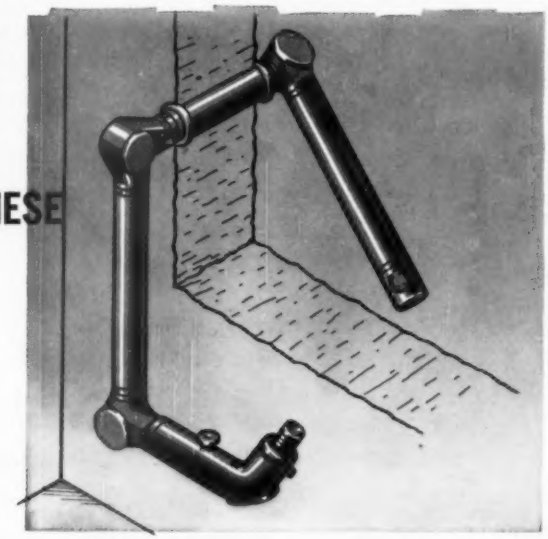

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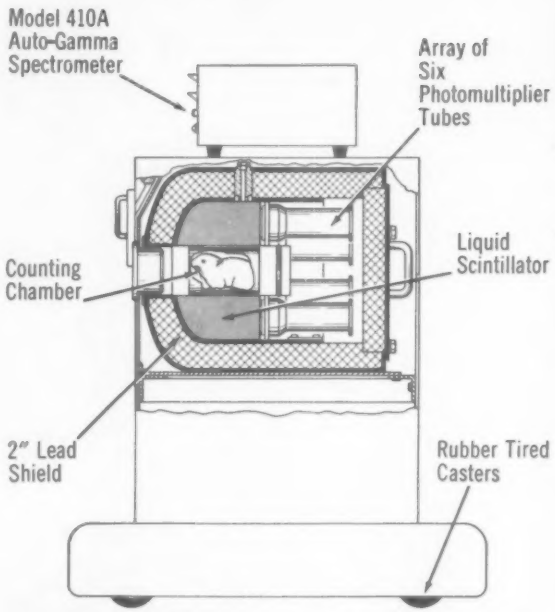

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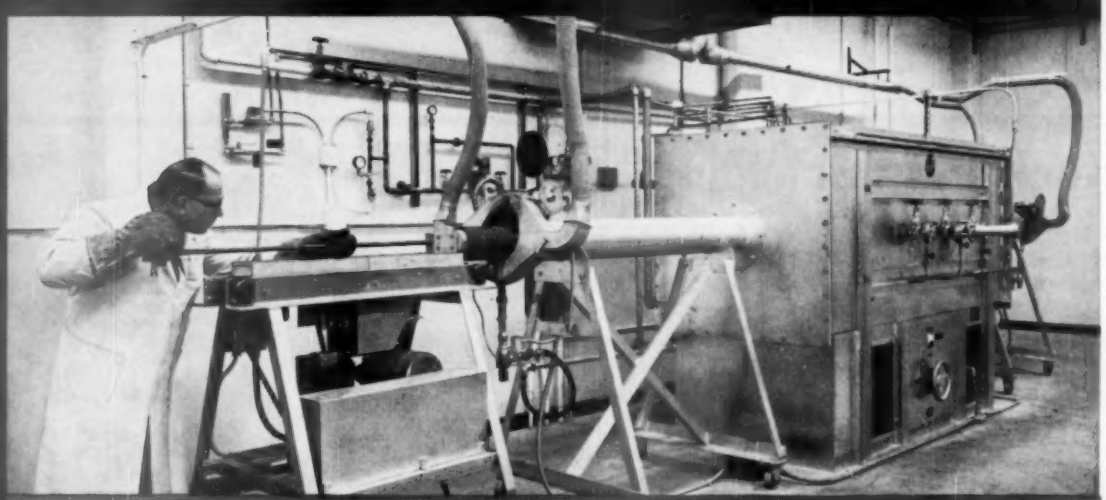

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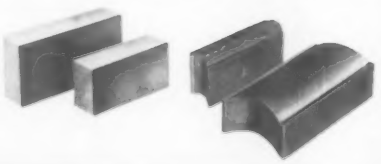

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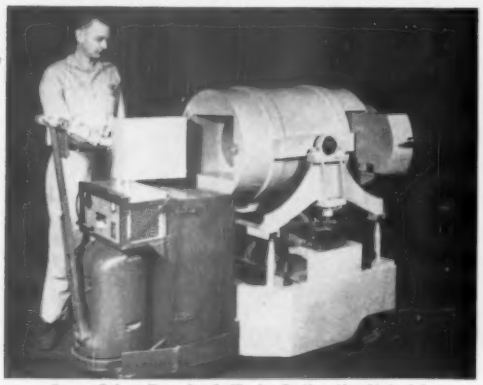
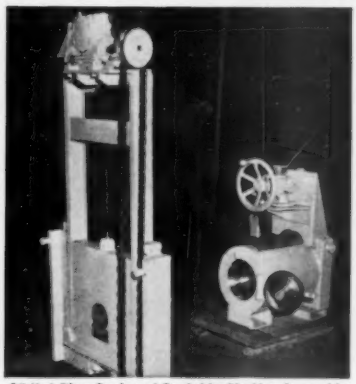


Power-Driven Transfer Coffin for Radioactive Material



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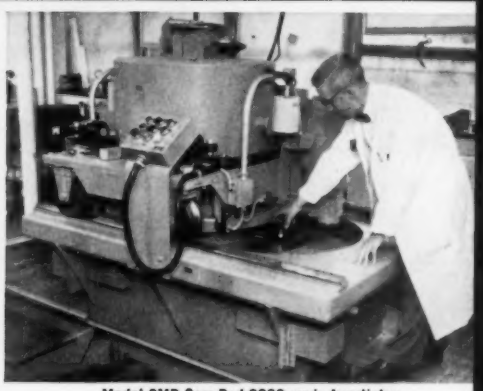

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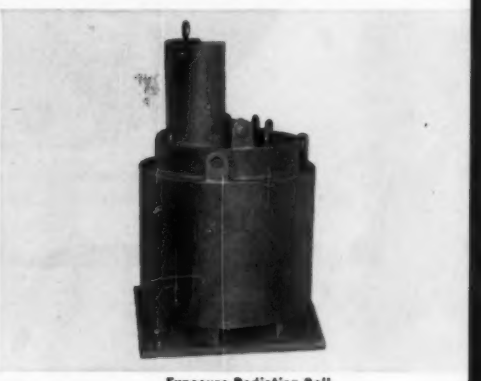
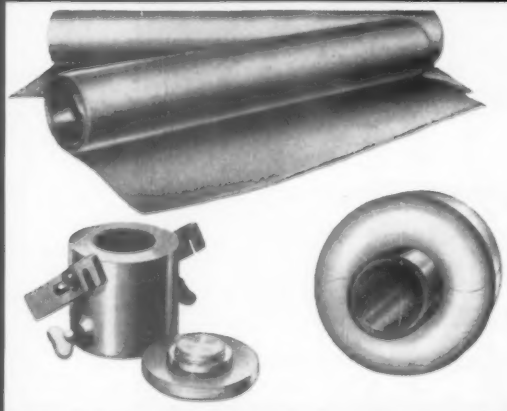


Exposure Radiation Cell



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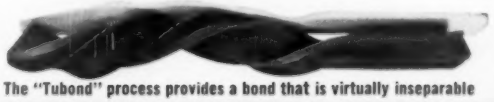
As the originator of "Tubond" lead products, widely used for over a half-century in the chemical processing fields, National Lead can supply bonded lead components where operating conditions entail efficient heat-exchange, vibration or mechanical abuse of equipment. The "Tubond" process assures the highest degree of overall bond of lead with its companion metal. When specified, ultrasonic testing equipment is employed to determine integrity of bond.



The "Tubond" process provides a bond that is virtually inseparable

Testing is carried out at outdoor ranges (left) or indoor laboratories (below)

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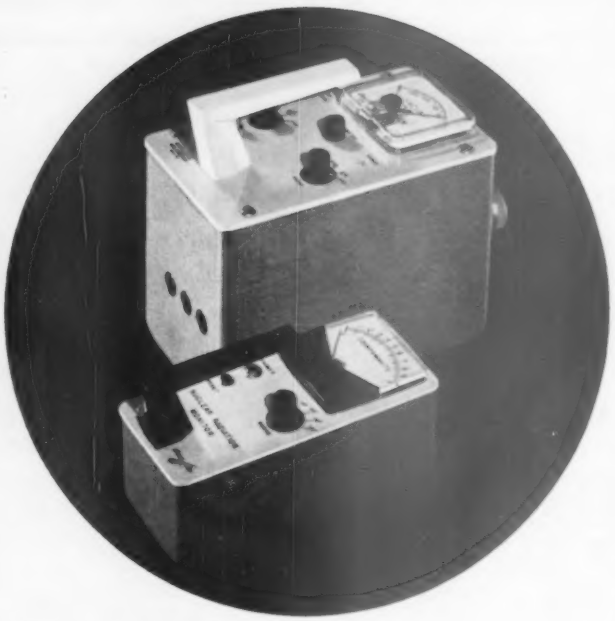

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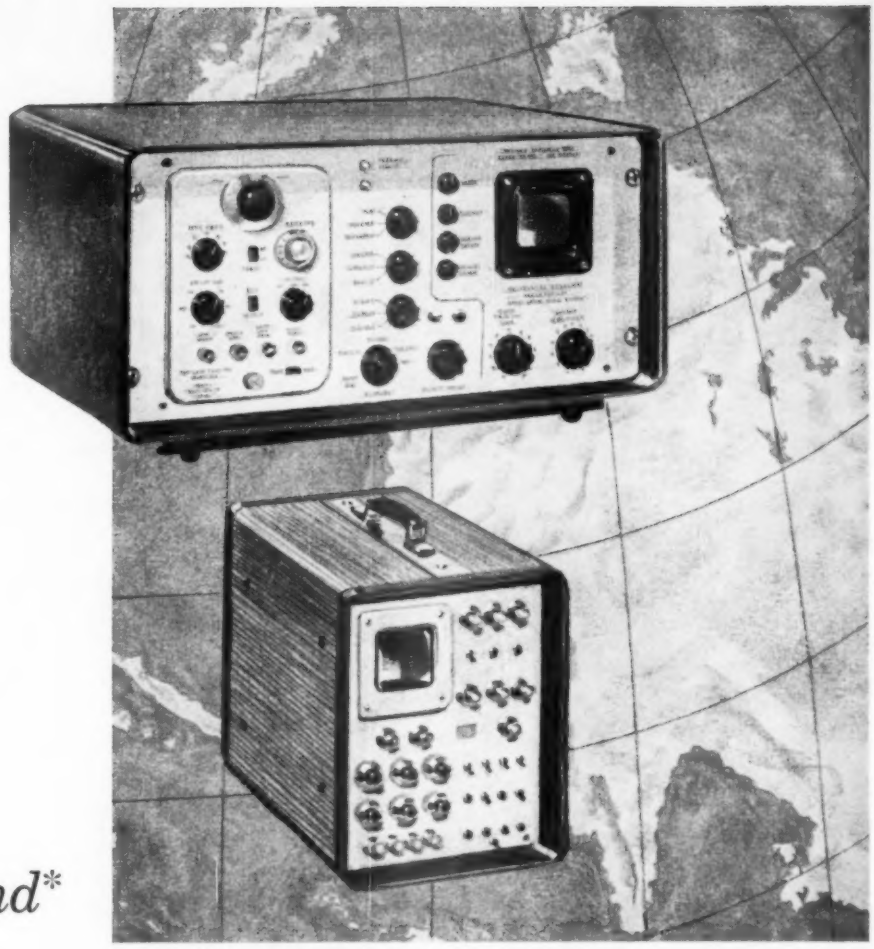

We think the reason people all over the world buy TMC pulse analyzers is pretty much the same reason they're widely purchased and used here: competently designed, bug-free circuits . . . straightforward operation with the same performance and stability today as yesterday . . . easy access to sub-assemblies and uncomplicated servicing if needed. Another way of putting it is the instruments give the user the information he wants in *his* work — with predictable behavior—regardless of where his site, lab or plant may be located. Here are two current examples:

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The Model 404 is a compact, 400-channel analyzer you can use anywhere there's a wall outlet and one square foot to put it down. It has a magnetic core memory that can be used in sub groups of two or four; four separate inputs and associated amplifiers; internal pulse routing circuity; pushbutton data transfer and display overlap; power requirement of *only 25 watts*, and many "system" advantages. While its versatility is a little less than the CN-110's, so are its size, price and purpose quite different from the 110's. Each does its *own* job well.

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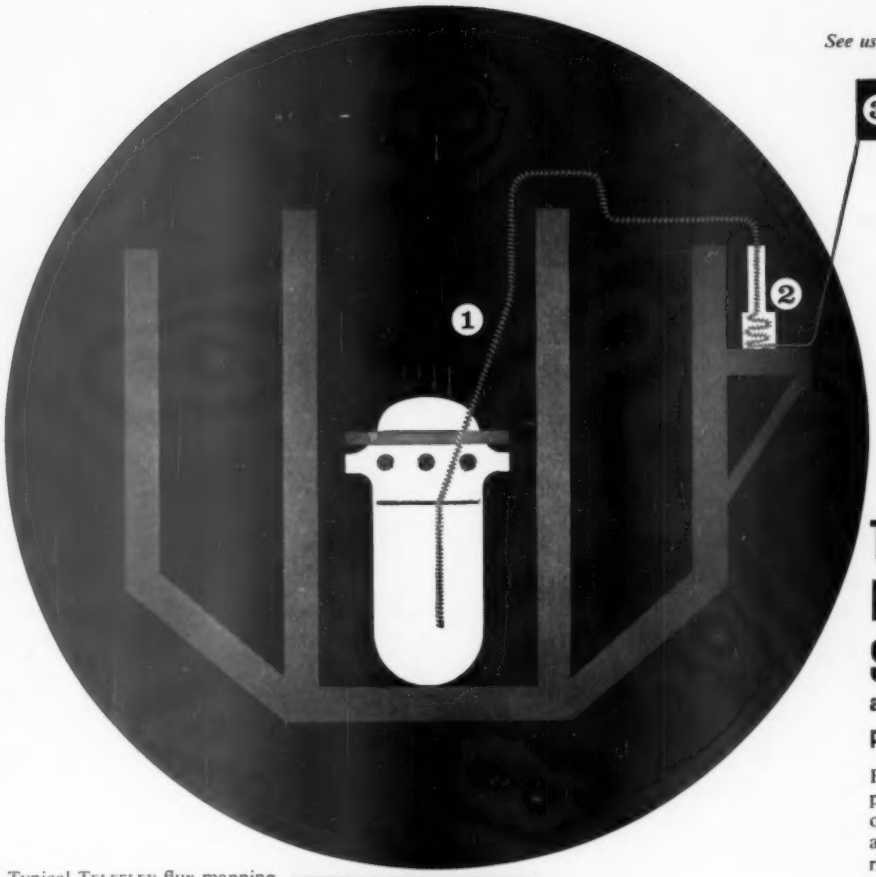

Typical TELEFLEX flux-mapping system, originating and remotely controlled from the safe vantage point of the main station control room.

TELEFLEX FLUX-MAPPING SYSTEMS give speedy, accurate core observations, power distribution control

Every feature of the TELEFLEX System points toward more effective control of reactor power capability. This advanced system produces accurate, reliable flux level measurements, and quickly . . . a complete map can be obtained in approximately one hour. As a result of more exact understanding of fuel burnup and control rod programming, more economical refueling techniques and more efficient core power distribution at all power levels is possible.

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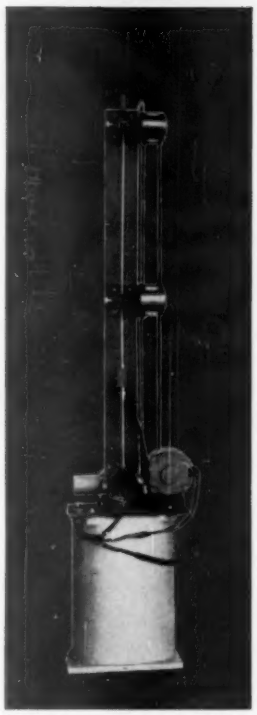

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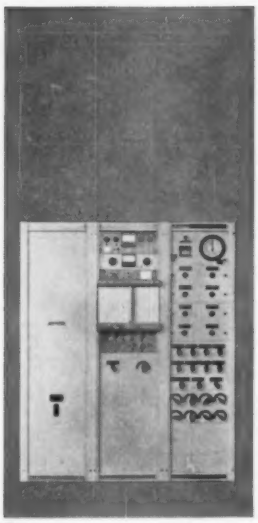

3. Remote control system includes counters, readout and recording devices; may be located anywhere.

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36YY

From scaffolding over core, B&W technician checks fuel element arrangement prior to criticality tests.

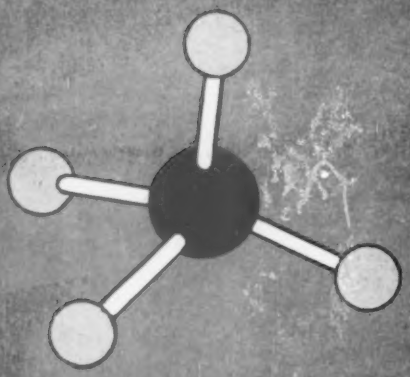
Con Edison core goes critical at B&W laboratories

On June 29, criticality was achieved in the thoria-urania fueled reactor core that will power Consolidated Edison's 275,000 kw Indian Point Station, now nearing completion.

Indian Point will be the nation's largest power plant employing nuclear power. Steam produced by the reactor will pass through oil-fired super-heaters, permitting turbine operation at 1000 F.

The full-core criticality tests, performed at B&W's Lynchburg, Virginia, nuclear facilities, are intended to confirm the nuclear design of the core. Further, important loading procedures to be used when the core is installed at Indian Point later this year will be determined. Pioneered by B&W, the unique thoria-urania fuel—with a conversion ratio providing extended core life—contains 93% thorium oxide. The Babcock & Wilcox Company, 161 East 42nd Street, New York 17, New York.

Babcock & Wilcox



A NUCLEONICS Special Report

RADIATION CHEMISTRY

For the chemist, as for many others who deal with it, ionizing radiation is many different things. It is a new ingredient: hydrogen and oxygen make water; hydrogen and oxygen and radiation make also some reactive species that do new things in test tubes. Radiation is also a promoting agent like heat: it can speed reactions, slow them and change their directions. It is also a tool: one can use it like a spectrometer to derive better understanding of how atoms react with one another.

In the following pages we have invited some of the world's busiest radiation chemists to summarize for the expert and introduce to the novice the exciting world of radiation chemistry.

One article, withheld to make more room for the others, will appear in a later issue of NUCLEONICS. It is on the subject of irradiation of catalysts and has been written for us by Ellison H. Taylor of Oak Ridge National Laboratory.

DIFFUSION KINETICS Aron Kuppermann . . . page 38
Tests of theory against experiment clarify the mechanisms basic to radiolysis

GASES Samuel C. Lind . . . page 43
Studies of gas reactions tell chemists about molecular and atomic behavior in medium

WATER Edwin J. Hart . . . page 45
Chemists probe into mysteries of reactions in water—the most important compound of all

ORGANICS John G. Burr . . . page 49
Chemists are developing kinetics for organic systems like those that apply in water

INTERMEDIATES IN LIQUIDS Leon M. Dorfman . . . page 54
Pulse-radiolysis methods enable direct observation of transient species in liquids

INTERMEDIATES IN SOLIDS Max S. Matheson . . . page 57
Although transients can be detected in solids, yields must be measured more accurately

HOT-ATOM REACTIONS John E. Willard . . . page 61
Atoms with abnormally high energies enter into unusual chemical reactions

POLYMERIZATION Adolphe Chapiro . . . page 65
A new knowledge of polymerization mechanisms points the way to commercial applications

DIFFUSION KINETICS

The more accurate calculations possible with computers show that the diffusion-kinetic model is capable of explaining many finer features of processes underlying radiation chemical reactions

by ARON KUPPERMANN, *University of Illinois, Urbana, Illinois*

WE HAVE KNOWN for a decade or two that as an ionizing particle passes through a chemical system—such as a dilute aqueous solution—a variety of interesting and often novel chemical reactions can take place along the particle's wake. We envision that the particle, through its ionizing action, leaves behind it a track of "spurs." These spurs are clusters of 2–12 free radicals with a diameter of 20–50 A, and usually have a concentration of ~1 mole/liter of radicals at the center (*1*, *2*). This dense concentration of newly formed radicals, then, as it diffuses outward, is where complicated interactions take place among various radical species that lead to the observed radiolytic products.

One can attempt a quantitative "diffusion-kinetic" description of these phenomena in terms of macroscopic reaction rate and diffusion laws. But the resulting differential equations contain, in addition to the time variable of homogeneous kinetics, space variables to describe the strong spatial inhomogeneity of the concentrations. These equations do not have general analytical solutions, but recently, high-speed electronic digital computers (*3–8*) have provided numerical solutions that avoid the gross approximations found necessary to solve these equations. As a result we can now perform calculations for systems involving two or three different kinds of radicals initially present, several kinds of reactive intermediates and several solutes. These calculations are helping us to understand not only the major effects of solute concentration and linear energy transfer (LET)* on yields, but also several "second order" (that is, small) effects such as the formation of HO_2 in de-aerated aqueous solutions, the crossover of the curves representing the molecular yields $G(H_2)$ and $G(H_2O_2)$ as functions of LET, most of the differences in yields between H_2O and D_2O solutions and the onset of dose-rate effects. They also reveal that some of the distributions proposed for initial radical concentrations are inconsistent with experiment unless the mechanism of formation of molecular products is other than by radical-radical reactions.

Eventually we might hope that this general radical-diffusion model of radiation chemistry will permit us to determine diffusion coefficients of interacting radicals as well as geometrical details of the tracks of energetic particles.

Stages in Radiolysis

The over-all process, which starts with bombardment of the system by energetic radiation and terminates with re-establishment of thermodynamic equilibrium in that system, can be conveniently divided into three stages (*10*):

• **Physical stage,** consisting of the dissipation of radiant energy in the system. Its duration is of the order of 10^{-13} sec or less (*11*). Absorption of radiation energy by a system results in production of a variety of excited species, such as electronically excited neutral molecules and ions in their ground or electronically excited states. In water or dilute aqueous solutions these ions are mainly H_2O^+. These species have a highly inhomogeneous spacial distribution and constitute the "tracks" of these radiations.

• **Physicochemical stage,** in which the energetically unstable excited species undergo a sequence of transformations that lead to the establishment of thermal equilibrium in the system. The duration of this stage is $\sim 10^{-11}$ sec for aqueous solutions. Products of these transformations are stable molecules, some of which differ from those originally present, plus chemically unstable species. In dilute aqueous solutions, these are believed to be H [or, possibly solvated electrons (*12*)] and OH free radicals. (I envisage a solvated electron as an electron that is attached to one or more water molecules by electrostatic interactions.)

• **Chemical stage,** consisting of diffusion and chemical reaction of the reactive species, and leading to the establishment of chemical equilibrium. It lasts from 10^{-8} sec upwards.

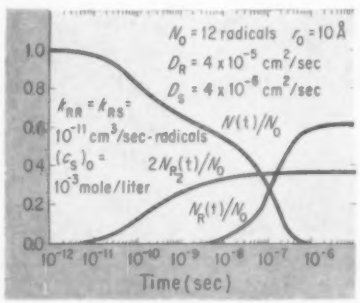


FIG. 1. RADICAL AND PRODUCT populations as functions of time

* Linear energy transfer (LET) is defined as the energy lost per unit length of path by the ionizing particle to the medium (for incident gammas, the ionizing particles are the Compton electrons).

Mathematical Formulation

Let us consider how to formulate a mathematical model of the diffusion-kinetic (or radical-diffusion) process that will allow us to calculate the amounts of each of the chemically stable products formed and to compare them with the experimental ones. We first assume that the chemically reactive "primary" species,* formed during the physicochemical stage, are in thermal equilibrium when the chemical stage starts. At this time they present a specific inhomogeneous spatial distribution which depends on the type and energy of the radiation used. These species then proceed to diffuse and react with themselves or with other species in the system. The products of these reactions may be "secondary" species—chemically unstable species that participate in further reactions.

All these reactions at any specific point are assumed to obey the same macroscopic diffusion- and reaction-rate laws as those that would be obeyed if all the reactive species were distributed homogeneously, except for one important difference—we substitute probability densities for the usual macroscopic concentrations.

The reason for this substitution is that the pronounced spatial inhomogeneity in the radical distributions would require that a concentration be defined in a volume element with linear dimensions less than that of a molecule, a definition that would be meaningless. The consequence of using such probability densities is that the resultant equations describe not the behavior of a single radical spur or track but the average behavior of a statistical ensemble of such spurs or tracks. Since, however, each experimental observation includes a very large number of spurs or tracks—a typical example would be 10^{14} tracks—this description is satisfactory.

Let $c_i(r,t)$ be the probability density (actually a generalized concept of concentration which, in the rest of this paper, we shall call simply concentration) of finding a particle of species X_i at the point r, at time t after the onset of the chemical stage. If the dose rate is low enough we can consider the chemical effects of different energetic particles or quanta as independent events. Then the time rate of change of the probability density c_i at r is the algebraic sum of the effects of the net rate of diffusion of particles X_i to this position and their rates of appearance and disappearance due to chemical reactions occurring there. If we assume that all these reactions are either first or second order, the corresponding equation is

$$\frac{\partial c_i(r,t)}{\partial t} = D_i\nabla^2 c_i - k_i c_i - \sum_j k_{ij} c_i c_j + \sum_l \bar{k}_{il} c_l + \sum_{m,n} \bar{k}_{m,n} c_m c_n \quad (1)$$

In this D_i is the diffusion coefficient of species X_i, ∇^2 is the usual three-dimensional Laplacian operator, k_i is a rate constant for a first-order disappearance of X_i, k_{ij} a second-order rate constant for the disappearance of X_i by reaction with X_j, k_l a first-order rate constant for the appearance of X_i from X_l and $\bar{k}_{mn}$ a second-order rate constant for the appearance of X_i by reactions of X_m with X_n. Thus the rate constants k refer to the disappearance of X_i whereas the $\bar{k}$ refer to its appearance. The number of Eqs. 1 is equal to the number of different reactive species X_i. For example consider a dilute oxygen-free aqueous solution of ferrous sulfate in 0.8 N sulfuric acid; the mechanism postulated (*13*, *14*) to explain the experimental facts is:

$$OH + OH \rightarrow H_2O_2\ (k_1) \quad (2)$$
$$H + H \rightarrow H_2\ (k_2) \quad (3)$$
$$OH + Fe^{++} \rightarrow OH^- + Fe^{+++}\ (k_3) \quad (4)$$
$$H + H^+ \rightarrow H_2^+\ (k_4) \quad (5)$$
$$H_2O_2 + Fe^{++} \rightarrow Fe^{+++} + OH + OH^-\ (k_5) \quad (6)$$
$$H_2^+ + Fe^{++} \rightarrow Fe^{+++} + H_2\ (k_6) \quad (7)$$

Here the different reactive species are OH, H, H_2O_2, H_2^+, Fe^{++} and H^+. [The first two are primary species, the next two secondary species and the last two are solutes (scavengers) present prior to irradiation.] A differential equation would be written for each of these six species. These would constitute a set of simultaneous nonlinear partial differential equations. Given the initial distributions $c_i(r,0)$† these equations can, in principle, be integrated by numerical methods, but not,

* The designation "primary" is improper, since these species are formed from other ones not initially present; nevertheless, it will be used for convenience.

† For solutes initially present, $c_i(r,0) = c_i(0,0)$ = constant; that is, the solute is homogeneously distributed at time zero. The distribution of the primary H (or $e^-\cdot H_2O$) and OH radicals depends, as Samuel and Magee (*3*) have pointed out, on the LET of the radiation under consideration. For radiations of low LET, such as Co^{60} gamma rays, the secondary energetic Compton recoil electrons are assumed to produce small spherically symmetrical spurs, containing about six radicals each, and far enough apart that they do not interact. Radiations of large LET, such as Po^{210} 5.3-Mev α particles, produce similar spurs but ones that are so close together that they effectively overlap, forming an axially homogeneous cylinder.

It is usually assumed, somewhat arbitrarily that the distributions of hydrogen and hydroxyl radicals within a spur are Gaussian with radii ranging from 10 to 150 A (*2*, *3*, *15*). Calculations have also been

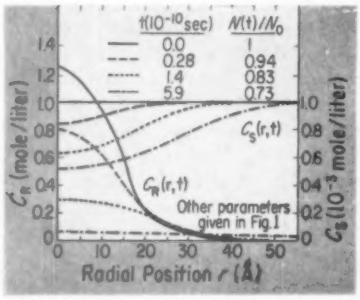


FIG. 2. RADICAL AND SOLUTE concentrations vs radial position

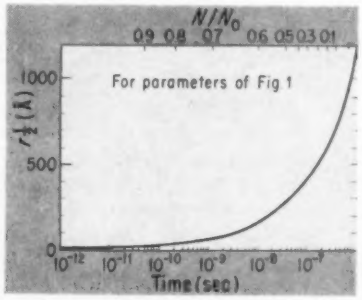


FIG. 3. RADIUS vs time and fraction of unreacted radicals for spherical spur

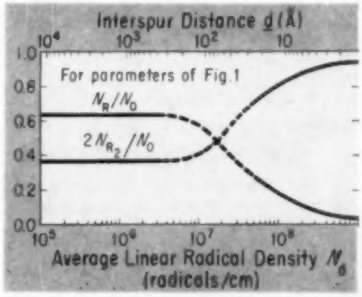


FIG. 4. RADICAL AND PRODUCT populations vs density N_d and interspur d

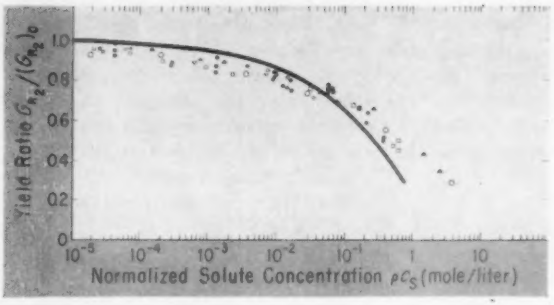


FIG. 5. MOLECULAR YIELD vs "normalized" solute concentration for Co^{60} gamma rays. Solid curve is theoretical

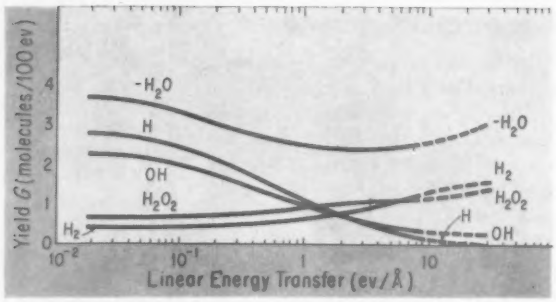


FIG. 6. MOLECULAR YIELD vs initial linear energy transfer for neutral aqueous solutions determined by experiment

in general, by analytical methods. Once they are integrated [that is, once the functions $c_i(r,t)$ are known], one can calculate the amounts of chemically stable products formed. For example, for the ferrous system mentioned above, the stable products of interest are H_2 and Fe^{+++}. Their total amounts are given respectively by

$$N_{H_2} = \int_0^\infty dt \int_{\text{system}} (\tfrac{1}{2} k_2[H]^2 + k_6[H_2^+][Fe^{++}])\, dr \quad (8)$$

$$N_{Fe^{+++}} = \int_0^\infty dt \int_{\text{system}} (k_3[OH] + k_5[H_2O_2] + k_6[H_2^+])[Fe^{++}]\, dr \quad (9)$$

where the quantities in brackets are the probability densities.

The quantities we want to compare with experiment are appropriate averages of these N's, which take into account the different spur sizes.

Let us assume that the incident radiation on the ferrous system consists of 1 Mev electrons at low dose-rates. The experiments would determine the radiation yields (G-number of particles formed per 100 ev of energy absorbed) for the formation of H_2 and Fe^{+++}. The theoretical problem is to calculate those values. To set initial conditions let us assume the OH and H initial distributions are Gaussian with radii of the order of 10A. If the incident electrons did not slow down and if no secondary electrons were produced, the spurs would be too far apart to interact and we could consider one spur at a time. Even for these conditions, however, different spurs may have different radii r_0 and different numbers of radicals N_0.

Once we pick values for r_0, N_0 and the diffusion coefficients and rate constants, we can procede to solve the set of six differential equations and calculate the quantities N_{H_2} and $N_{Fe^{+++}}$ from Eqs. 8 and 9. We must next choose a value of 2ω, the energy necessary to form a radical pair.

The ratios $N_{H_2}/N_0\omega$ and $N_{Fe^{+++}}/N_0\omega$ would then furnish the G values if all spurs had the same r_0 and N_0. Because they probably do not, we must pick a reasonable distribution function for these two quantities and repeat the calculations for several sets of values. The values of $N/N_0\omega$ are then averaged according to this distribution function. The averages $<N/N_0\omega>$ obtained would be the theoretical G values if the two assumptions mentioned above were correct. But since the incident electrons do slow down and secondary electrons are produced, one must take these effects into account (*16, 17*) to arrive at quantities to be compared with experiment. Comparisons that neglect these effects can only be considered as semiquantitative.

Criticism of Model

The assumptions in the diffusion-kinetic model that macroscopic diffusion and reaction rate laws are valid for spurs and tracks as long as concentrations are replaced by probability densities is equivalent to neglecting correlation between the particles (*18*). At least some correlation should exist, but just how much has not been investigated.

Another assumption of the model is that at the beginning of the chemical stage the primary reactive species exist in thermal equilibrium with the surrounding medium. This assumption precludes the possibility of unconventional chemistry during the physicochemical stage (*10*); for example, in water, which has a full dielectric relaxation time of $\sim 10^{-11}$ sec, reactions involving ions and occurring in times smaller than this might be quite different from those occurring when the medium has had time to relax. Also the physicochemical and chemical stages can overlap. Reactions can occur before thermal equilibrium is attained and can involve excited species; or occur simultaneously with energy transfer processes. The amount of energy going into chemical reactions, and hence the G values, would thus be influenced.

An apparently serious criticism of the model is that it contains so many unknown parameters that by an appropriate choice of their values, it should always be possible to fit experiment. On the other hand these parameters, at least in principle, are measurable by independent experiments. As a result the flexibility that the model has due to our ignorance of their values is not a permanent one.

This temporary flexibility should be viewed as an inadequacy of the present state of experimental knowledge about the properties of radicals in solution, among other things, rather than a weak point of the model. If all rate constants and diffusion coefficients were known, the model could be stringently tested even in the absence of accurate knowledge of the initial distribution parameters. The reason is that these depend, for a given medium and physical conditions, only on the type and energy of the radiation used, and are invariant with respect to other experimental variables such as the nature and

(*Footnote continued*) made for non-Gaussian distributions (*9*).

For either isolated spherical spurs or axially homogeneous cylindrical tracks the single space dimension r (the distance to the center of the spur or to the axis of the track) is sufficient to describe the spacial distribution of radicals.

concentration of solutes. Thus, the number of experimental results to be explained could be much larger than the number of unknown initial distribution parameters.

In conclusion the only test of the adequacy of the model at present can be the extent to which it quantitatively explains the experimental facts, suggests new experiments and forecasts their results. Simplified forms of the model have been quite successful in this connection and fast digital computers can now subject the model to stricter tests. In the following sections we describe some of the results obtained so far.

One-Radical Models

The simplest model that takes into account diffusion of radicals and reaction of radicals with solute is

$$R + R \rightarrow R_2 \quad (k_{RR}) \quad (10)$$
$$R + S \rightarrow RS \quad (k_{RS}) \quad (11)$$

R represents the radicals, S the solute and the k's the rate constants.

For the spherical spurs let $N(t)$, $N_{R_2}(t)$ and $N_R(t)$ be respectively the number of radicals at time t and the number of R_2 and RS molecules formed up to time t. For the cylindrical case, let these symbols represent the equivalent linear densities, that is, the numbers of radicals or molecules per unit length of track.

If we use the symbol N_0 to represent $N(0)$ and N_{R_2} and N_R to represent $N_{R_2}(\infty)$ and $N_R(\infty)$ respectively, then $2N_{R_2}/N_0$ and N_R/N_0 are the fractions of the initial number of radicals that undergo the recombination reaction of Eq. 10 and the solute reaction of Eq. 11. The quantities N_{R_2}/N_0 and N_R/N_0 are called fractional molecular and radical yields respectively, and are to be related to the experimental primary molecular and free radical yields.

In Figs. 1–3 the several quantities of interest are plotted against time or distance from center for a particular spherical Gaussian spur (*8*). Initial conditions are given by

$$c_R(r,0) = \frac{N_0}{(2\pi)^{3/2} r_0^3} e^{-r^2/2r_0^2} \quad (12)$$

The radical-radical reaction is over in about 10^{-8} sec and the radical-solute one in about 10^{-6} sec. Although, as seen in Fig. 3, the solute concentration at the center of the spur at $t = 5.9 \times 10^{-10}$ sec is about half its initial value, calculations show that practically the same final yields would have been obtained if no such decrease had occurred. For cylindrical tracks, however, the solute depletion at the center of the track can cause an increase in the fractional molecular yields of 15%.

In Fig. 4 the radical and twice the molecular yields are plotted against the average linear radical density N_d and the interspur distance d, for a track consisting of a string of identical equidistant Gaussian spherical spurs. The left-hand portions of the curves correspond to sufficiently large interspur distances for the spurs to be considered isolated and the right-hand portions to distances sufficiently small for the track to be almost axially homogeneous. The dashed intermediate region was obtained joining the other two smoothly, and in it neither of the two previous approximations are valid.

Theory and Experiment

As we have said, our calculations cannot be quantitatively compared with experiment because they do not take into account the distribution of spur sizes and interspur distances, the formation of delta-rays, etc. In addition most of the calculations performed up to now were aimed not at obtaining an exact quantitative agreement between theory and experiment (since too many unknown parameters are yet involved) but at developing a feeling for the quantitative properties of the model. Therefore the comparison with experiment that we will give here is inherently semiquantitative in nature. The next stage in the development of diffusion kinetics will, however, be the pursuit of a quantitative agreement.

Solute concentration. Experiments (*19–25*) on several systems, find that the yields of molecular products decrease as the concentration of solute increases. For Co^{60} gamma rays graphs of $G(R_2)/[G(R_2)]_0$ against c_S, obtained with different solutes, can, to a good approximation, be superimposed by horizontal translation. [R_2 stands for either H_2 of H_2O_2; $G(R_2)$ for concentration c_S of solute S and $[G(R_2)]_0$ is the value of this yield extrapolated to zero solute concentration.] In Fig. 5 experimental points (*21, 26*) for $G(H_2)/[G(H_2)]_0$ and $G(H_2O_2)/[G(H_2O_2)]_0$ are plotted against log $[\rho c_S]$; the value $\rho = 1$ was arbitrarily chosen for NO_3^- as the solute and H_2 the molecular product, and the other values of ρ for each combination of solute and molecular product were chosen to make all points fall on the same curve. The solid curve on the same figure is that derived by approximate methods by Schwarz (*21*) and also by diffusion-kinetic calculations of myself and Belford (*8, 9*).

The superposition of the curves by horizontal translation is explained as follows. Because the solute depletion in the center of spherical spurs does not affect the calculated fractional yields, the diffusion equation for the solute can be neglected. It follows that the effect of solute on yields appears only through the product $k_{RS}(c_S)_0$ which appears in the diffusion equation for the radicals, $(c_S)_0$ being the initial solute concentration.

Since different solutes have different values of k_{RS}, the superposition described is expected and the value of ρ should be a measure of the ratio of k_{RS} for solute S and radical R to $k_{H+NO_3^-}$. This is indeed found to be so for the few cases in which the relative rate constants are known (*21*).

In spite of the reasonable agreement, a definite difference in curvature between the theoretical and experimental curves of Fig. 5 does, however, exist. This difference persists when a distribution function for N_0 and r_0 is used, with either N_0/r_0 or N_0/r_0^3 maintained constant. Change of a one-radical to a two-radical model or of the shape of the initial distribution from Gaussian to rectangular is also ineffective (*8, 9*). A possible improvement might be a consideration of the effects of delta rays (*16, 17*).

When $N_{R_2}/(N_{R_2})_0$ is plotted against $(c_S)_0^{1/6}$ the curve obtained has a linear portion over a range of about 3 to 4 orders of magnitude of the solute concentration. This is the so-called cube-root law, but no special meaning should be attributed to it because plots against other powers of c_{S0} such as $\frac{1}{2}$ would also produce linear portions over appreciable concentration ranges. This $\frac{1}{6}$-power agreement is essentially accidental.

Linear energy transfer. As the LET of the radiation increases, the molecular yields $G(H_2)$ and $G(H_2O_2)$ increase and the radical yields G_H and G_{OH} decrease. (See Fig. 6, obtained by Dyne and Kennedy (*6*) from the data of Schwarz and his colleagues (*21*) for neutral water.) Qualitatively the experimental and theoretical curves are

similar, and the value of 20 ev to form a radical pair in water is consistent with a simple two-radical model calculation. Physically, the reason that in cylindrical tracks the molecular yields are larger than in isolated spherical spurs is that the appreciable overlap of neighboring spurs in the former case produces much higher radical concentrations along the track than those in the center of the isolated spurs. Figure 6 also shows that although at small LET $G(H_2) < G(H_2O_2)$, at large LET $G(H_2) > G(H_2O_2)$. Such an effect has been obtained in a two-radical model which includes the reaction $H + H_2O_2 \rightarrow OH + H_2O$ (*8, 9*).

Initial distributions. Figure 6 indicates that for Co^{60} gamma rays (LET = 0.02 ev/A) $G(H_2)/G(H_2O_2)$ is about 0.65. Calculations on a two-radical model (*8, 9*) require that the ratio of the initial radii of the H and OH distributions be smaller than three for the calculated yield ratio to agree with the experimental one. The diameter ratio of about seven or eight suggested by Lea (*2, 15*) or the even larger ones by Platzman (*10, 27*) are thus inconsistent with the diffusion-kinetic model. The value of unity for the initial r_H/r_{OH} ratio suggested by Samuel and Magee (*3, 27*) cannot be excluded by these calculations.

HO_2 formation. Some investigators suggest (*28, 29*) that the reaction $OH + H_2O_2 \rightarrow HO_2 + H_2O$ occurs in the spurs or tracks of high-energy particles in water. The yield $G(HO_2)$ of this reaction is 0.02 molecule/100 ev for Co^{60} gamma rays (*28*) and 0.23 molecule/100 ev for 5.3-Mev alpha particles (*29*). These values and the other experimental radical and molecular yields furnish for the ratio $G(HO_2)/[2G(H_2) + G(H) + G(HO_2)]$ the value 0.005 for the former and 0.050 for the latter radiation. Calculations for a two-radical model including this reaction with a rate constant of about one tenth of the radical-radical reactions furnished equivalent ratios of 0.007, and 0.070 respectively (*8, 9*), without any attempt at obtaining accurate agreement with experiment.

H_2O and D_2O yields. The table below summarizes some recent data for yield ratios in solutions of ferrous sulfate in 0.8 *N* sulfuric acid in light and heavy water irradiated by 220 kvp x-rays (*30*). It has been suggested that these results can be explained (*30, 31*) by assuming that the deuterium distribution in heavy water is broader than the hydrogen distribution in ordinary water, the OD and OH ones having equal radii. The second row of the table gives results of calculations (*9, 32*) made using a two-radical model, with $r(OH) = r(OD) = 10$ A, $r(H) = 20$ A and $r(H) = 25\Delta$. Except for the $G(H_2O_2)/G(D_2O_2)$ ratio, the calculated ones are on the same side of unity as the experimental ones. No explanation for the exception has yet been found. Equivalent data for neutral rather than acid solutions would be interesting.

Experimental and Calculated Yield Ratios

	$G(H_2)/G(D_2)$	$G(D)/G(H)$	$G(OD)/G(OH)$	$G(H_2O_2)/G(D_2O_2)$	$G(-D_2O)/G(-H_2O)$
Experimental	1.21 ±0.05	1.11 ±0.03	1.05 ±0.06	1.04 ±0.05	1.03 ±0.04
Calculated	1.21	1.05	1.02	0.97	1.02

Dose-rate effects. Sutton and Rotblat (*33*), using 15-Mev electrons from a linear accelerator, have studied the effect of very high dose rates (up to 2×10^{10} rads/sec) on Fe^{+++} yields in aerated-acid ferrous-sulfate solutions and on Ce^{+++} yields in aerated-acid ceric-sulfate solutions. They have suggested that the results obtained can be explained by assuming that at these high dose rates radicals originating in different tracks react with each other. From the space-time history of spherical spurs obtained from diffusion calculations it is possible to make estimates of the minimum dose-rates necessary for such reactions to occur. For a simple one-radical model and the parameters of Fig. 1 [except that k_{RS} is taken as 10^{-12} (rather than 10^{-11}) $cm^3/(sec \times radic)$], this lower limit turns out to be (*8*) about 1.2×10^8 rad/sec which is just about where those authors start seeing dose-rate effects.

* * *

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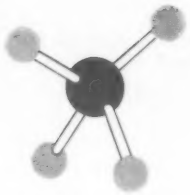


GASES

In one- or multicomponent irradiated-gas systems a wide variety of different reactions occur that help radiation chemists find out more about chemical effects in gaseous matter

by SAMUEL C. LIND, *Oak Ridge National Laboratory,* Oak Ridge, Tennessee*

IN GASES atoms and molecules enter into different reactions when exposed to radiation than they do in solids or liquids. These reactions—induced primarily by ionizing or exciting agents from accelerators, reactors or radon—affect either one-component systems, as in the case of ozone formation in oxygen, or more usually multicomponent ones. In the latter systems, for example, oxidation, hydrogenation and polymerization as well as charge-transfer and energy-transfer reactions in foreign gases play an important role. In addition reverse reactions occur when one-component systems dissociate under radiation to become multicomponent ones.

Absorption of Radiation

Because of their large dispersion, gases absorb energy sparingly from ionizing agents—the largest amount is from alphas or protons, much less from beta particles and electrons and an almost negligible amount from gammas.

The heavier a molecule is, the greater is its absorption. Quantitative relations between numbers of ionizing molecules and numbers that react suggest a relation between the two. Either ions attach directly to neutral molecules and react on neutralization or they dissociate to free radicals that induce reaction.

Radiation Sources

In radiation chemistry of gases two useful sources are reactors and radon.

Reactors. Most gas reactions under pile irradiation are studied to learn how radiation affects gas coolants or by-products in reactors. Results show that when it is used as a coolant in a graphite reactor, carbon dioxide is reduced to carbon monoxide by reacting with the carbon. In addition mixtures of nitrogen and oxygen gas (30% O_2 in mixture) oxidize in pile to nitrogen monoxide for nitric-acid production.

Radon. Although reactors are important, the most convenient radiation source of all is radon. It mixes homogeneously with all gases, has a useful half-life of 3.825 days, emits radiation evenly, and neither it nor its helium atoms react. In addition straight-line alpha-particle (He^{++}) paths allow one to calculate ionization easily.

One-Component Gas Reactions

Because it takes place in our own atmosphere, ozonization of oxygen by alpha particles is the best known one-component reaction. The ion yield is two ozone molecules for each ion pair $[M^+(O_3)/N(O_2)]$ (Fig. 1). The yield, however, is limited severely by the reverse effect of oxygen attacking ozone in the long-chain reverse reaction $[M^-(O_3)/N(O_2) = 15{,}000$ or greater]; this multiplying effect explains the small ozone yield.

Multicomponent Reactions

In multicomponent systems important reactions involve oxidation, hydrogenation, polymerization, reverse reactions and foreign gases.

Oxidation is one of the most interesting multicomponent reactions because oxygen makes a double contribution. It not only ionizes to positive ions (O_2^+), but also captures electrons to form negative ones (O_2^-). Both ions can then dissociate to neutral atoms (O) and atomic ions (O^+ and O^-) and in doing so promote oxidation.

Some of these reactions are oxidation of hydrogen to water and peroxide

* Operated by Union Carbide Corp for U. S. AEC.

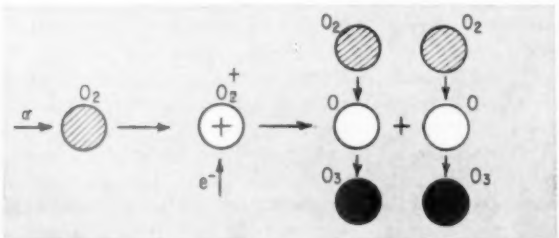


FIG. 1. OZONE FORMATION is most important one-component reaction. For each ion pair, yield is two ozone molecules

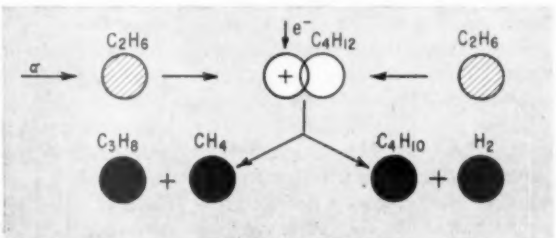


FIG. 2. IN CONDENSATION OF ETHANE polymerization occurs with elimination of hydrogen five times as often as that of methane

(H_2O_2); carbon monoxide to carbon dioxide; hydrocarbons to water, carbon dioxide and partial oxidation products; ammonia (NH_3) to water and oxides of nitrogen; cyanogen (C_2N_2) to a yellow polymer [$(CNO)_x$]; nitrogen gas to oxides of nitrogen; and acetylene (C_2H_2) to carbon monoxide, carbon dioxide and a colorless liquid polymer [$(C_2H_2)_x$] with small vapor pressure and little or no oxygen content. Little water is produced in acetylene oxidation by radon.

If oxygen is mixed with gas that ordinarily undergoes some reaction of its own, oxidation usually occurs rather than the other reaction. This property is called "exclusivity of oxidation." For example, in the reactions above, carbon monoxide does not give free carbon or C_3O_2 polymer, but rather carbon dioxide; cyanogen does not polymerize to black paracyanogen; acetylene does not form a solid cuprene; and methane (CH_4) or ethane (C_2H_6) with oxygen gives water and carbon dioxide instead of hydrogen gas or higher hydrocarbons.

Hydrogenation. Because it has no affinity for electrons, hydrogen does not form negative ions by attachment. Its positive ions are less reactive than oxygen ions and thus do not exclude other reactions. Although ethylene (C_2H_4) or acetylene mixed with hydrogen are not hydrogenated by radon but undergo their own reactions as if hydrogen were not present, acetylene has been both hydrogenated and polymerized simultaneously by 2-Mev electrons. In addition vapor-liquid partition chromatography reveals about 12 hydrocarbons—both saturated and unsaturated. Nevertheless polymerization of ethylene to liquid polymer predominates.

Cyanogen differs from the unsaturated hydrocarbons, acetylene and ethylene, because it is hydrogenated by radon. From a mixture of equal parts of hydrogen and cyanogen the reaction ratio is $2H_2{:}3C_2N_2$ indicating an unknown product $H_4C_6N_6$—a black polymer resembling that from cyanogen alone. The two-to-three reaction ratio remains constant while the gas ratio changes from the initial one-to-one ratio to one part of cyanogen to 100 parts of hydrogen toward the end of the reaction. This proves a definite product composition. Hydrogenation is not, however, exclusive because some nitrogen gas is liberated and probably some ammonia forms.

Other hydrogenation reactions include $H_2 + D_2 \rightarrow 2HD$ and the long-chain reaction $H_2 + Cl_2 \rightarrow 2HCl$, which is much inhibited by impurities. In the latter reaction chains up to 5×10^5 units have been measured and in even greater purities they become explosive. The long-chain Nerst mechanism is $Cl_2 \rightarrow 2Cl$; $Cl + H_2 \rightarrow HCl + H$; $Cl_2 + H \rightarrow HCl + Cl$.

Polymerization of unsaturates. Gas polymerizations can be classified in at least two ways. First, they can be classed by the number of initial molecules in one polymer unit. Under this classification fall two subgroups: (a) those with a large indefinite number of molecules depending on pressure, temperature and intensity of ionization and (b) those with a small (3–20) number of units, independent of conditions including contributions of inerts. Second, they may be classed by polymerization: (a) those with elimination of products like hydrogen gas or methane from the hydrocarbon parent and (b) those without elimination as for example acetylene. The first of these subgroups is more properly called "condensation" (Fig. 2), and it must occur in hydrocarbons condensing to higher members as in the reactions

$$2CH_4 \rightarrow H_2 + C_2H_6 \text{ or}$$
$$2C_2H_6 \rightarrow CH_4 + C_3H_8$$

Since it has a small, definite polymer-chain length and eliminates both hydrogen gas and methane, ethylene when it condenses represents both the second subgroup under the first classification and the first subgroup under the second. This compound is midway between acetylene and ethane in ion yield and elimination.

Reverse reactions. As stated earlier, most reactants that begin with one component dissociate under radiation and become multicomponent. When this happens the dissociation products may recombine to reverse the reaction. Recombination can take place immediately or by slower reverse reactions. The small yield in radiolysis from reactions with large heat of formation such as water vapor or carbon dioxide make one suspect that these are rapid recombination reactions. This suspicion is confirmed for water by examining radiolysis at liquid-air temperature; recombination is so slow that normal values of M^-/N ($\sim$8) are achieved for radiolysis.

Because of the small heats of reaction in either direction, reversal in radiolytic reaction of organic molecules is not prominent.

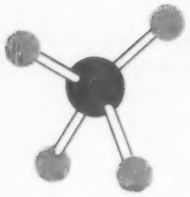
Foreign gases that cannot react with a primary gas may instead contribute to its reaction by absorbing radiation energy and transferring it to the reactant; the inert gas later returns to its inactive state, thus maintaining its concentration. Exhaustion of the reactant rapidly diminishes its proportion relative to inert gas so the probability of transfer and experimental ion yield both fall. This phenomenon is known as depletion and may explain the drop in yield as a reaction proceeds in a static system—especially near the end of the reaction.

The polymerization reactions discussed earlier are subject to energy and charge transfer induced by the ions of foreign gases. A remarkable feature of the reactions is their large efficiency. For example in acetylene polymerization the efficiency is practically 100%; thus an inert gas ion in acetylene is just as effective as ionized acetylene because of the large efficiency of charge transfer. The mechanism of this catalytic reaction is simple charge transfer from inert ions of larger ionization potential to the reactant molecule.

Mass Spectrometry

Although mass spectrometry greatly aids study of charge transfer between gases, it has certain disadvantages: its small operation pressure ($\sim$1 mm Hg) limits collision transfer, and the rapid sweep of gases from the ion chamber prevents observation of large ion-molecule complexes by addition. Nevertheless mass spectrometry is a very useful tool. Indeed it is a kind of small-pressure radiation chemistry that measures exact relative masses of ions.

When mass spectrometry is applied to mixtures of any noble gases with acetylene or cyanogen it has three types of transfer: (1) without addition, (2) with addition and (3) with addition followed by dissociation leaving the reactant changed and the inert neutral. In addition partial molecular dissociation occurs in mass spectrometry and may even predominate over intact molecules, though it must later be repaired by recombination. For example in acetylene-xenon mixtures, although the complex $(C_2H{\cdot}Xe)^+$ is abundant, the final product is solid cuprene [$(C_2H_2)_{20}$] without free hydrogen gas.



WATER

Studies of irradiated pure water and aqueous solutions not only settle free-radical mechanisms, but also answer questions about energy transfer, diffusion kinetics and yields in H_2O molecules

by EDWIN J. HART, *Argonne National Laboratory, Argonne, Illinois*

THE MOST IMPORTANT COMPOUND of all is water because every biological system and most chemical ones contain it. Consequently chemists study radiation effects in pure water and aqueous solutions to learn more about reaction mechanisms and to try to answer their questions about how reactions affect materials containing water molecules.

Early work in radiolysis of water indicated that hydrogen, hydrogen peroxide and oxygen are decomposition products. More recent studies have settled the mechanism for some free-radical reactions. In addition, investigations with both pure water and aqueous solutions have answered some of the chemist's questions on hydrogen and hydroxyl free-radical yields, diffusion kinetics and identification of species generated in irradiated water (*1–16*).

Irradiated Pure Water

Concepts of water ionization and excitation by radiation are extremely simple. In the former process a Compton recoil electron (e_c^-) ionizes water producing H_2O^+, secondary electrons (e_s^-) and a lower-energy Compton recoil electron (e_c^-) by

$$H_2O + e_c^- \rightarrow H_2O^+ + e_s^- + e_c^-$$

Excitation, on the other hand, occurs either by the primary or secondary electron and dissociates water by the reactions

$$H_2O \rightarrow H_2O^*$$
$$H_2O^* \rightarrow H + OH$$

[H_2O^* represents water molecules in any excited or super-excited state (*17*).]

This dissociation reaction is a relatively efficient one even for 1,849 A excitation (*18*). The water ion and the secondary electron also produce these radicals by the processes

$$H_2O^+ + H_2O \rightarrow H_3O^+ + OH$$
$$H_2O + e_s^- \rightarrow e_{aq}^-$$
$$e_{aq}^- \rightarrow H + OH^-$$

(e_{aq}^- is hydrated electron.) The net reaction is

$$H_2O^+ + e_s^- \rightarrow H + OH$$

A basic difference exists between photolysis and radiolysis of water. In photolysis, excitations are distributed at random through the irradiated volume according to light-absorption equations. In radiolysis, however, because of the prevalence of low-energy secondary-electron ejectures, isolated "spurs" or energy-rich zones appear along the track of the ionizing particle (see article p. 38, this issue). In these spurs water molecules dissociate in a short time compared to that needed for appreciable diffusion.

In the spurs—~20 A in radius—initial radical concentration approaches 1*M* (*19*). Subsequent radical-radical

TABLE 1—Systems for Measuring Yields in Irradiated Water (8)

System	*Simplified equation*
O_2, Br^-	$G(H_2O_2) = g(H_2O_2) + \frac{1}{2}[g(H) - g(OH)]$
O_2, H_2	$G(H_2O_2) = g(H_2O_2) + \frac{1}{2}[g(H) + g(OH)]$
Fe^{++}, O_2	$G(Fe^{+++}) = 2g(H_2O_2) + 3g(H) + g(OH)$
Fe^{++}	$G(Fe^{+++}) = 2g(H_2O_2) + g(H) + g(OH)$
D_2	$G(HD) = g(H)$
Ce^{++++}	$G(Ce^{+++}) = 2g(H_2O_2) + g(H) - g(OH)$ $G(O_2) = g(H_2O_2)$
Fe^{++}, Cu^{++}	$G(Fe^{+++}) = 2g(H_2O_2) - g(H) - g(HO_2) + g(OH)$ $G(O_2) = g(HO_2)$
Fe^{+++}, HCOOH Fe^{+++}, CH_3OH Fe^{+++}, Cu^{++}, HCOOH, O_2	$G(Fe^{++}) = g(H) + g(OH)$
$CH_2 = CHCONH_2$, Fe^{+++}	$G(Fe^{++}) = g(H) + g(OH)$ (*23*)
HCOOH, O_2	$G(H_2O_2) = g(H_2O_2) + \frac{1}{2}[g(H) + g(OH)]$ $G(CO_2) = g(OH)$ $G(-O_2) = \frac{1}{2}[g(H) + g(OH)]$ $G(H_2) = g(H_2)$
Boiling water	$G(H_2) = g(H_2)$ $g(H) + 2g(H_2) = g(OH) + 2g(H_2O_2)$

TABLE 2—Radiation Yields in Air-Free 0.8 N Sulfuric Acid and Air-Saturated Water (9)

Radiation	$g(H)$	$g(OH)$	$g(H_2)$	$G(H_2O_2)$	$g(H_2O)$	*Total* $g(H_2O)$
			Air-free 0.8 N sulfuric acid			
Co^{60} γ-rays	3.65	2.95	0.45	0.80	−4.55	
Co^{60} γ-rays*	3.70	2.92	0.39	0.78	−4.48	
18-Mev D^+	2.39	1.75	0.71	1.03	−3.81	
8-Mev D^+	1.71	1.45	1.05	1.17	−3.80	
32-Mev He^{++}	1.28	1.06	1.14	1.25	−3.56	
$B^{10}(n,\alpha)Li^7$	0.23	0.41	1.66	1.57	−3.54	
			Air-saturated water			
Co^{60} γ-rays	2.78	2.28	0.42	0.67	−3.70	−4.76
18-Mev D^+	2.90	2.36	0.40	0.67	−3.89	−4.42
32-Mev He^{++}	1.55	1.13	0.66	0.87	−2.78	−4.65
11-Mev He^{++}	1.65	1.07	0.62	0.91	−2.57	−4.84

* Aerated solutions.

reactions lead to hydrogen and hydrogen peroxide—the so-called molecular products of water radiolysis (*20*). The spur reactions are $H + H \rightarrow H_2$ and $OH + OH \rightarrow H_2O_2$ and the water reconstitution reaction is $H + OH \rightarrow H_2O$.

Obviously these radicals combining within the spur produce no chemical change to added solutes and only radicals escaping these reactions are effective (see article p. 38).

As more is learned about reactions in irradiated water, it becomes clear that all reactions are not explained by free-radical mechanisms. But even today, little confidence can be placed in any detailed mechanism.

Among the several additional intermediate species postulated, the solvated electron or polaron is important because of its abundance and high reactivity with solutes (*21, 22*). Hydrogen atoms produced by $OH + H_2 \rightarrow H_2O + H$ behave differently from hydrogen formed by ionizing radiations (*21*), the implication being that at least the reactive reducing species in irradiated water may be e_{aq}^- instead of hydrogen.

Other species include the hydroperoxy radical, HO_2, the dissociation products from hydroxyl, hydroperoxy and H_2^+ radicals and water subexcitation electrons (*9*).

Linear energy transfer (LET). Radiations commonly used in studying aqueous solutions are electrons, x-rays, gamma rays, protons, deuterons, helium ions and recoil fragments from nuclear disintegrations of B^{10}, Li^7 and U^{235}. The light particle group—electrons, x-rays and gamma rays—efficiently produces hydrogen and hydroxyl free radicals whereas the heavy particle group produces large amounts of molecular hydrogen and hydrogen peroxide. Consequently reactions that need free radicals for their initiation are promoted by light-particle radiations, and reactions requiring hydrogen peroxide (and not hydroxyl radicals) are efficiently promoted by heavy-particle radiations.

The simultaneous irradiation of water by combinations of gamma-ray and proton or gamma-ray and electron radiations gives additive effects for simple nonchain reactions such as oxidation of ferrous sulfate. Thus although the majority of dosimetric reactions are unaffected by mixed radiations, chain reactions are affected. A notable example is decomposition of water irradiated in reactors. Under reactor conditions the large gamma-ray component of reactor radiations effectively suppresses the water decomposition initiated by proton recoils in water used as a neutron moderator. The chain sequence

$$OH + H_2 \rightarrow H_2O + H$$

and

$$H + H_2O_2 \rightarrow OH + H_2O$$

provides the mechanism by which the hydrogen and hydrogen peroxide generated in the proton and gamma-ray spurs react to form water: $H_2 + H_2O_2 \rightarrow 2H_2O$.

Radiation yields. Important in promoting chemical effects are free-radical and molecular products yields of radiations. The basic radiolysis equation is (*9*)

$$(2a + c - e)H_2O = aH_2 + bH_2O_2 + cH + dOH + eHO_2$$

If expressed in molecules reacted or formed per 100 ev of energy absorbed, the coefficients a to e help in explaining

TABLE 3—Free-Radical Reactions in Aqueous Solutions (28)

Hydrogen atoms

$H + D_2 \rightarrow HD + D$
$D + H_2 \rightarrow HD + H$
$H + O_2 \rightarrow HO_2$
$H + paraH_2 \rightarrow orthoH_2 + H$
$H + H_2O_2 \rightarrow H_2O + OH$
$H + Fe(H_2O)_a^{++} \rightarrow Fe^{+++}(H_2O)_{a-1} + OH^- + H_2$
$H + Ce^{++++} \rightarrow Ce^{+++} + H^+$
$H + Fe^{+++} \rightarrow Fe^{++} + H^+$
$H + Cu^{++} \rightarrow Cu^+ + H^+$
$H + I_2 \rightarrow H^+ + I^- + I$
$H + NO_2^- \rightarrow NO + OH^-$
$H + N_2O \rightarrow N_2 + OH$ (*29*)
$H + CO_2 \rightarrow COOH$ (*30*)
$H + Tl^{+++} \rightarrow Tl^{++} + H^+$
$H + Hg^{++} \rightarrow Hg^+ + H^+$ (*31*)
$H + Ag^+ \rightarrow Ag + H^+$ (*31*)
$H + HSO_4^- \rightarrow H_2SO_4^-$
$H + MnO_4^- \rightarrow MnO_4^{--} + H^+$
$H + CrO_4^{--} \rightarrow CrO_3^- + OH^-$
$H + H_3AsO_3 \rightarrow H_2AsO_3 - H_2O$

Hydroxyl radical

$OH \rightleftarrows O^- + H^+$
$OH + D_2 \rightarrow HOD + D$
$O^- + O^{16}O^{18} \rightarrow O^{18-} + O^{16}O^{16}$
$O^{18}H + HO^{16}O^{16}H \rightarrow O^{16}H + HO^{18}O^{16}H$ (*25*)
$OH + H_2O_2 \rightarrow H_2O + HO_2$
$OH + Fe^{++} \rightarrow Fe^{+++} + OH^-$
$OH + Ce^{+++} \rightarrow Ce^{++++} + OH^-$
$OH + Tl^+ \rightarrow Tl^{++} + OH^-$
$OH + I^-, Br^-, Cl^- \rightarrow I, Br, Cl + OH^-$
$OH + NO_2^- \rightarrow OH^- + NO_2$
$OH + HSO_4^- \rightarrow OH^- + HSO_4$
$OH + NH_3 \rightarrow NH_2 + H_2O$
$OH + MnO_4^- \rightarrow MnO_4^{--} + H^+ + O$ (*32*)
$OH + Cr^{+++} \rightarrow Cr^{++++} + OH^-$
$OH + H_2AsO_3 \rightarrow H_2AsO_3 + H_2O$

Hydroperoxy radical

$HO_2 + H_2O_2 \rightarrow H_2O + O_2 + OH$
$2HO_2 \rightarrow H_2O_2 + O_2$
$HO_2 + Fe^{++} \rightarrow Fe^{+++} + HO_2^-$
$HO_2 + Fe^{+++} \rightarrow Fe^{++} + H^+ + O_2$
$HO_2 + Ce^{++++} \rightarrow Ce^{+++} + H^+ + O_2$
$HO_2 + Cu^{++} \rightarrow Cu^+ + H^+ + O_2$
$HO_2 + MnO_4^- \rightarrow MnO_4^{--} + H^+ + O_2$

TABLE 4—Radiolysis and Basic Yields in Dilute Aqueous Organic Solutions

Oxygen-free solutions

$G(H_2) = g(H_2)$ (dehydrogenation of solute does not occur).
$G(H_2) > g(H_2)$ (some dehydrogenation of solute does occur).
$G(H_2) = g(H_2) + g(H)$ (each H removes one H from solute).
$g(H_2) < G(H_2) < g(H_2) + g(H)$ (H atoms add to solute).
$G(H_2O_2) = g(H_2O_2)$ (intermediate free radicals do not react with H_2O_2).
$G(H_2O_2) < g(H_2O_2)$ (some intermediate free radicals react with H_2O_2).

Solutions with oxygen

$G(H_2) = g(H_2)$ (each H reacts with O_2).
$G(H_2) > g(H_2)$ (some H abstracts H from solute).
$G(H_2O_2) = \frac{1}{2}g(H) + g(H_2O_2)$ (HO_2 radicals do not react with solute).
$G(H_2O_2) = \frac{1}{2}[g(H) + g(OH)] + g(H_2O_2)$ (HO_2 radicals originate by reactions like: $COOH + O_2 \rightarrow CO_2 + HO_2$).
$G(H_2O_2) \gg g(1+) + g(OH)$ (oxygen initiates chain reaction).
$G(-O_2) = \frac{1}{2}g(H)$ (H react with O_2; HO_2 only with HO_2).
$G(-O_2) = \frac{1}{2}[g(H) + g(OH)]$ (O_2 reacts with H and with organic radicals formed from OH; peroxy radicals then liberate O_2).

radiation effects and deducing reactions mechanisms. I will use "G" to denote experimental yields such as yield of hydrogen peroxide, $G(H_2O_2)$, and will designate radical and molecular yields by "g" such as $g(H_2O_2)$. Thus g's are fundamental radiation parameters for a medium.

By adding solutes reactive with hydrogen atoms, hydroxyl radicals and hydrogen peroxide and by using product yields, G's, one can deduce g's (Table 1). Note that, in general, only one or two yields can be measured from a single system.

Table 2 lists yields for several radiations. In this table $g(H)$ denotes the sum of the radical-type reducing species whether it is the hydrogen atom, the solvated electron or some as yet unknown entity. Yields are slightly different in heavy water and depend somewhat on pH (*23, 24*).

Aqueous Solutions

Because hydrogen and hydroxyl radicals form water from hydrogen peroxide and hydrogen, pure water undergoes no apparent decomposition when irradiated by light-particle radiations. By using free-radical scavengers such as iodide ion, however, or by stripping hydrogen from the solution during irradiation one can decompose water. When irradiated by heavy particles water produces hydrogen and hydrogen peroxide initially. Subsequently the hydrogen peroxide decomposes into water and oxygen. The dividing line between radiations showing a net decomposition and those not decomposing is not clearly defined, but if $g(H) + g(OH) > g(H_2) + g(H_2O_2)$, pure water does not decompose.

Free-radical reactions of hydrogen, oxygen and hydrogen peroxide are summarized in Table 3. The overall free radical induced reactions are

$$H_2O + D_2 \rightarrow HDO + HD$$
$$H_2O + \tfrac{1}{2}O_2 \rightarrow H_2O_2$$
$$H_2O^{16} + O^{16}O^{18} \rightarrow H_2O^{18} + O^{16}O^{16}$$
$$H_2O_2 \rightarrow H_2O + \tfrac{1}{2}O_2 \text{ (chain at } [H_2O_2] > 0.01\ M)$$
$$H_2 + O_2 \rightarrow H_2O_2$$
$$H_2 + H_2O_2 \rightarrow 2H_2O \text{ (chain)}$$

(Figures in square brackets indicate concentrations.) The deuterium atom does not exchange with water at room temperature (*26*).

The large reducing power of hydrogen and the large oxidizing power of the hydroxyl radical promote chemical changes in dissolved molecular or ionic species. General oxidation and reduction reactions are:

$$M^{n+} + OH \rightarrow M^{(n+1)+} + OH^-$$
$$M^{n+} + H \rightarrow M^{(n-1)+} + H^+$$

A special case is a reaction between reducing species and dissolved oxygen. Either of the following equivalent reactions proceeds rapidly: $H + O_2 \rightarrow HO_2$ and $e_{aq}^- + O_2 \rightarrow O_2^-$. As a result oxygen affects reactions and is very effective at concentrations as small as 10^{-5}–10^{-6} M. In general oxygen converts the reducing hydrogen atom into the oxidizing HO_2 radical and thus alters chemical yields. To eliminate the effect of oxygen extreme care must be taken.

A partial list of inorganic reactions is given in Table 3. With a knowledge of the free-radical (H, OH, HO_2) and hydrogen-peroxide reactions, one may use Table 4 to estimate yields of products formed on irradiation. For example in oxidation of aerated ferrous sulfate $G(Fe^{+++}) = 3g(H) + g(OH) + 2g(H_2O_2)$ because each hydrogen atom is converted to HO_2, which can oxidize three ferrous ions, each hydroxyl radical oxidizes one ferrous ion and each hydrogen peroxide two ferrous ions. Similarly $G(Ce^{+++}) = g(H) - g(OH) + 2g(H_2O_2)$. Here the hydrogen atom (or hydroperoxy radical) and hydrogen peroxide reduce ceric ions whereas hydroxyl radical oxidizes cerous ions. (*Continued*)

TABLE 5—Free-Radical Reactions With Organic Compounds in Water

Hydrogen atom	*Hydroxyl radical*
$H + CO \rightarrow HCO$	$OH + CO \rightarrow COOH$
$H + CO_2 \rightarrow COOH$	$OH + CH_4 \rightarrow CH_3 + H_2O$
$H + CH_4 \rightarrow CH_3 + H_2$	$OH + C_2H_4 \rightarrow CH_2CH_2OH$
$H + C_2H_4 \rightarrow C_2H_5$	$OH + C_6H_6 \rightarrow C_6H_5 + H_2O$
$H + C_6H_6 \rightarrow C_6H_7 \rightarrow$ polymer	$C_6H_5 + OH \rightarrow C_6H_5OH$
$H + RCH_2OH \rightarrow RCHOH + H_2$	$OH + RCH_2OH \rightarrow RCHOH + H_2O$
$H + HCHO \rightarrow CHO + H_2$	$OH + HCHO \rightarrow CHO + H_2O$
$H + HCOOH \rightarrow HCOO(COOH) + H_2$	$OH + HCOOH \rightarrow HCOO(COOH) + H_2O$
$H + NH_2CH_2COOH \rightarrow NH_2CHCOOH + H_2$	$OH + NH_2CH_2COOH \rightarrow NH_2CHCOOH + H_2O$
$H + NH_2CH_2COOH \rightarrow CH_2COOH + NH_3$	$OH + CHCl_3 \rightarrow CCl_3 + H_2O$
$H + CHCl_3 \rightarrow CHCl_2 + HCl$	$OH + C_6H_5Cl \rightarrow C_6H_4Cl + H_2O$
$H + C_6H_5Cl \rightarrow C_6H_5 + HCl$	$OH + RSH \rightarrow RS + H_2O$
$H + RSH \rightarrow RS + H_2$	

Considerable progress has been made in studying hydrogen and hydroxyl radical reactions with organic molecules. Because of the complex structure of the compounds irradiated, however, with few exceptions detailed free-radical mechanisms are largely speculative. Evidence shows that the subexcitation electron as well as the hydrated electron play roles in these reactions (*22, 27, 33, 34*).

General reactions of these radicals with organic substrates in aqueous solutions are summarized in Table 4. Here one sees that hydrogen atoms not only dehydrogenate the solute but also add to it without liberating hydrogen. Since water is the normal oxidation product of hydroxyl reaction with organic molecules, direct observation of dehydrogenation is more difficult than with hydrogen atoms. Besides hydrogen-atom abstraction, hydroxyl-radical addition to organic free radicals has been observed. Typical reactions of hydrogen and hydroxyl radicals with organic compounds are given in Table 5.

In dilute acidified solutions hydrogen atoms prevail and the reactions in Table 5 take place. In neutral or weakly acid solutions, however, hydrogen-atom or hydroxyl-atom abstraction may possibly result from the organic molecule. With formic acid a hydrogen atom may form by $e_{aq}^- + HCOOH \rightarrow HCOO^- + H$ or an HCO radical by $e_{aq}^- + HCOOH \rightarrow HCO + OH^-$. Under these conditions the hydrated electron introduces a formyl radical that changes the course of the reactions.

Additional reactions are possible too as the solute concentration increases. For example (1) as indicated above, the solute may compete with water for capturing the solvated electron; (2) it may become excited by water subexcitation electrons and yield normal photodissociation products; and (3) it may have a large capture cross section for these subexcitation electrons. Little is known, however, about details of these reactions and their contribution to radiation effects remains speculative.

* * *

This article is based on work performed under AEC auspices.

Applications of Radiation Chemistry in Water

In chemistry, ionizing radiations supplant photochemistry as a convenient way to generate hydrogen atoms and hydroxyl radicals in de-aerated water. In addition hydroperoxy radicals rapidly replace hydrogen atoms in oxygenated solutions. Many laboratories are studying relative rate constants among reactions initiated by hydrogen, hydroxyl and hydroperoxy, and since yields of these radical species are known, they provide a powerful tool for deducing free-radical mechanisms. In addition the recent introduction of high-intensity pulsed electron beams offers a way to measure absolute rate constants of radical-radical and radical-solute reactions (see p. 54; also 35, 36).

Much progress has also been made in diffusion-kinetics research. As soon as the reaction-rate constants and distribution of free radicals along electron and heavy-ion tracks become known, a better understanding of radical-diffusion processes in water will be possible.

Why mammals are so sensitive to radiation also remains an unsolved mystery. But because of the preponderance of water in body tissue, a knowledge of reactions of hydrogen and hydroxyl radicals with biologically sensitive molecules is crucial in providing an explanation. A conspicuous correlation exists between the effect of dissolved oxygen in the chemical and biological action of radiations. In chemical systems, oxygen is important because of the very large reaction rate constant with hydrogen atoms and electrons. In biological systems, this factor doubtless plays a role, but here, too, oxygen reacts with secondary organic free radicals formed from the primary hydrogen and hydroxyl radicals. Progress toward understanding biological reactions is being made by studying thiols, amino acids, carbohydrates, proteins, enzymes, nucleates, vitamins, sterols and cyochromes.

For water decomposition and corrosion problems in water-moderated reactors one needs a clear perception of basic reactions. The apparent stability of water in high-flux reactors is deceptive as operating experience with Argonne's Experimental Boiling-Water Reactor showed (37). In this reactor water decomposition was traced to the stripping of hydrogen from the aqueous phase which prevents the water reconstitution reaction, $H_2 + H_2O_2 \rightarrow 2H_2O$ (38). By using available knowledge from radiation-chemistry research, one can accelerate fundamental studies of the effect of mixed radiation such as gamma rays, recoil protons and fission fragments on water stability and the effect of hydrogen atoms, hydroxyl and hydroperoxy radicals on corrosion of reactor materials.

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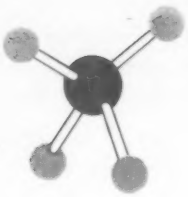

ORGANICS

Organic radiation chemistry needs reaction kinetics like those that explain aqueous reactions so that one can compare theory and experiment. New techniques make such comparisons possible

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ULTIMATELY THE ABILITY to predict behavior in a chemical system—the goal of any material science—depends on a detailed understanding of microscopic behavior. Today there is an exciting possibility that we can obtain quantitative knowledge of the important reaction mechanisms in organic radiation chemistry. Since few large-yield products come from most classes of organic compounds, we know that the number of such mechanisms is small.

Current techniques are removing many experimental barriers to such investigations. Gas chromatography and growing use of mass spectrometry have so simplified product separation and quantitative analysis, so quickened measurements and so increased accuracy that these items are no longer major problems. Although a seemingly inherent irreproducibility of data still plagues mechanism investigation, more and more discrepancies are being traced to real causes, important for understanding the mechanisms (*1*).

What is Happening

Let us concentrate on a few developments that appear to offer hope for understanding mechanisms of organic radiation chemistry. The principal trend in these developments is toward quantitative and kinetic language such as will be found elsewhere in this series of articles to describe aqueous systems. Organic radiation chemists must develop a slightly new terminology because in their systems the concept of a track is not as well defined as in aqueous ones (see figures, next page). Since hydrogen atoms, radicals and other reactive entities from decomposition of an organic molecule can react with most of the surrounding molecules, it is more difficult to speak of a particular, sharply delineated volume element where radical recombination is the principal or exclusive process. In particular there appears to be little or not hydrogen-atom recombination in liquid organic systems.

Effect of Physical State

Change from gas to liquid to solid is one method for altering concentrations of reactant molecules. One would prefer concentration changes accomplished by diluting the reactants with an inert solvent, but there are no inert solvents in organic radiation chemistry (except perhaps liquid cyclopropane, which is unusually inert to radical attack).

Irradiation of organic solids is probably attended by the same solid-state complications as irradiation of solid-state water (*2*), but it appears that transition from liquid to solid should not greatly affect products formed by unimolecular dissociation of excited organic molecules nor products formed by small atoms such as hydrogen, which are known to diffuse rapidly even in solid organics (*3*). Such transitions should affect measurably the yield of products formed by bulky radicals which should not be able to diffuse readily in solids.

Observations that hydrogen and methane yields from cyclohexane are the same in liquid and solid phases (*4, 5*) agree with the concept that these products arise by a combination of unimolecular dissociation and hydrogen-atom or methyl-radical reactions. On the other hand hydrogen yield from benzene shows a sharp three-fold drop as temperature falls below the melting point (*5*). In our laboratory we have

Radiation Chemistry and Reactor Coolants

Discussion of linear-energy-transfer (LET) effects is particularly pertinent for radiolysis of aromatic hydrocarbons since polyphenyl hydrocarbons are moderator-coolants for most organic-moderated reactors. Since these moderators see a mixed flux of fast neutrons and gamma rays, it is of practical importance to know the relative effect of large-LET particles and small-LET gamma rays in decomposing the polyphenyl. Fast neutrons should clearly have a LET effect rather than a knock-on-collision effect.

It has been calculated that 28 collisions in terphenyl will thermalize a 2-Mev neutron—16 collisions with hydrogen and 12 with carbon atoms (9). Average energy of the ejected proton in the first collision is 1 Mev, of the carbon, 0.28 Mev. These recoil protons and carbon ions will eject other atoms to give a total of about 500 molecules damaged by knock-on collisions. On the other hand ~1 Mev of ionization damage results from this first collision—about 10,000 molecules damaged—if the destruction coefficient (negative *G* value) is 1 molecule/100 ev.

observed that hydrogen yields from biphenyl and terphenyl show a similar sharp drop as one goes to the solid state (Table 1) (*6*).

A significant measure of phase-change effect is comparison of one- and two-molecule reaction rates. For example

$$C_{12}H_{10} \rightarrow SE + H_2 \quad (1)$$

$$C_{12}H_{10} + C_{12}H_{10}^* \rightarrow C_{12}H_9—C_{12}H_9 \text{ (or SE)} + H_2 \quad (2)$$

(We use "SE" to mean some molecule, fragment or collection of fragments and molecules other than the reactant molecule—that is, "something else.")

Unimolecular dissociation (Eq. 1) probably would not be greatly affected by phase change whereas the bimolecular reaction (Eq. 2) should be largely inhibited. Thus we take the great reduction in hydrogen yield with change to solid (Table 1) to mean that the principal mechanism is probably something corresponding to Eq. 2 with only very small contribution by Eq. 1.

The lack of change in hydrogen composition is more baffling. Perhaps the hydrogen originates in the molten region of a thermal spike in the solid. As another example, a ten-fold increase in iodine-molecule yield in going from solid to liquid alkyl iodides (*7*) (yield of hydrogen iodide does not change much) is consistent with conclusions that iodine production in radiolysis is by bimolecular reaction of alkyl-iodide molecules (*8*):

$$2RI \rightarrow R_2 + I_2 \quad (3)$$

LET and Dose Rate

Concentration-change effects can be induced not only by abrupt change in density of target molecules (phase changes) but also by alterations in the volume density of excited molecules, ions and radicals. Such changes are usually accomplished either by changing dose rate or by changing from a lightly ionizing radiation, like an electron beam, to a densely ionizing radiation, like protons.

Sometimes competitions among mechanisms give information on LET effects. We have thought (*6, 10*), for example, that formation of hydrogen in radiolysis of aromatic hydrocarbons is by bimolecular collisions of excited molecules with themselves or unexcited molecules in a single-step process, that polyphenyl dimer originates by a similar process and that polymer results, on the other hand, from a series of radical-scavenging processes (*11*).

If hydrogen and biphenyl arise from the same reaction in benzene and this reaction is between an excited benzene molecule and an unexcited benzene molecule, radiation of larger LET will produce a greater concentration of excited benzene molecules. Consider, for example, the following mechanism:

$$ArH^* + ArH = H_2 + Ar\text{-}Ar \quad (4)$$

$$ArH^* + ArH = 2ArH \quad (5)$$

$$ArH^* + ArH^* = Ar\text{-}Ar + H_2 \quad (6)$$

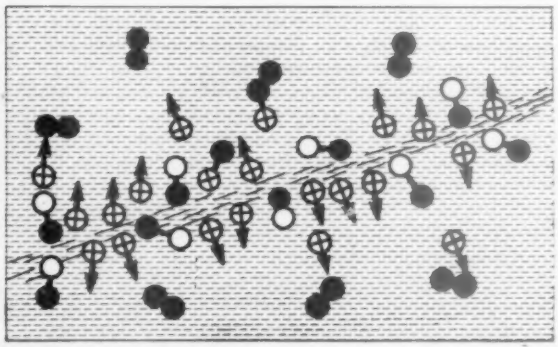
Hydrogen and biphenyl yields are probably the net result of the competition between Eqs. 4 and 5. If only these two reactions are involved, there should be no LET effect on hydrogen or biphenyl yield. But if hydrogen and biphenyl arise from a process like Eq. 6 or if Eq. 6 is at all important, hydrogen and dimer yields should increase with increasing LET. Actually hydrogen yield increases with LET but in no regular manner, and the yield of biphenyl is independent of LET (*12*). Thus the two products are probably not formed by the same process, neither Eq. 4 nor Eq. 6.

We have gained further evidence in recent measurements of the yield of high boilers (HB) (defined as all products less volatile than *o*-terphenyl) from

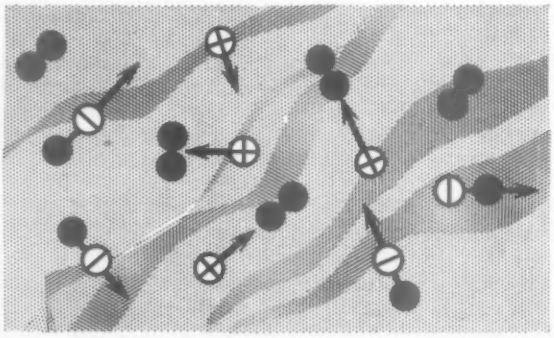
TABLE 1—Hydrogen Yield from Irradiated Solid Biphenyls

Sample	*Phase*	*Total yield* (10^{-3} *molecules/100 ev*)	$\%H_2$	$\%HD$	$\%D_2$
Biphenyl	Solid*	0.522	100		
	Liquid†	7.68	100		
Biphenyl-d_{10}	Solid	0.284	5.5	4.0	90.5
	Liquid	2.49	3.6	5.9	90.5
50-50 mixture of biphenyl and biphenyl-d_{10}	Solid‡	0.544	53.6	29.6	16.8
	Solid§	0.564	54.7	26.6	18.7
	Liquid	5.01	60.3	27.6	12.2

* Solid 42°C. † Liquid 100°C. ‡ Gas recovered by distillation of sample. § Gas recovered by sublimation of sample.



IN AQUEOUS SYSTEMS well defined tracks permit one to deal with volumes in which radical recombination predominates



IN ORGANIC SYSTEMS decomposition products can react with most of their surroundings; thus track concept disappears

TABLE 2—Polymer from *o*-Terphenyl*

Temperature (°C)	Total dose (10^{20} rads)	Destruction coefficient (molecules/100 ev)
60	1.1	0.40
100	1.6–4.6	0.51
150	1.5–3.0	0.63
200	1.2–2.5	0.74
250	1.2–1.7	0.83
300	1.4–1.5	0.90

* Under irradiation by ~1.5-Mev Po^{210} alpha particles.

irradiation of *o*-terphenyl with Po^{210} alpha particles of ~1.5 Mev (LET = 15 ev/A) (*13*). Results, over a temperature range of 60–300°C, are shown in Table 2. The plot of destruction coefficient (negative G-value) corresponds to an apparent activation energy of 1 kcal/mole. This is very small, much smaller than activation energies for addition of radicals to double bonds or the propagation step of most vinyl polymerizations. It suggests that energetic radicals are important in initiating formation of the polymer.

If the 300°C data are plotted with existing data for electron irradiation of *o*-terphenyl (*13*) and an average value of the destruction coefficient for terphenyls (*14*) (there is a large spread in these values), a linear relationship is apparent between LET and destruction coefficient. This may be fortuitous, but it can be partly rationalized if we consider that the HB yield is proportional to initial radical concentration.

Radicals, Energy Transfer

Perhaps the most rapidly advancing, quantitative and generally productive area of organic radiation chemistry is that of radical scavenging and energy transfer. If the systems and reactions I am about to describe can be really well understood, they offer tools by which we can properly examine the effects of many other variables in organic radiolysis and thus rapidly introduce more system into this bewildering field.

Advances that have been made are not the result of measurement of total radical yield (*15*, *16*), determined by disappearance of iodine, formation of organic iodides (*15*), loss of DPPH (*16*) or rates of polymerization initiation (*16*). Such figures have not provided much information about mechanisms, and there is some doubt about whether hydrogen atoms are always thus counted (*17*). Rather the yield of a particular product such as molecular hydrogen or methane as a function of scavenger concentration has provided the great gain in knowledge when such effects have been interpreted in terms of radical scavenging (*17–19*) rather than energy transfer (*20–22*). The radical-scavenging interpretation is based on a simple kinetic competition (for example the following equations for hydrogen-molecule formation):

Equation	Rates	
$RH^* \rightarrow SE + H_2$	$G_m(H_2)$	(7)
$RH^* \rightarrow R' + H$	$G(H)$	(8)
$H + RH \rightarrow H_2 + R''$	$k(H), k(RH)$	(9)
$H + S \rightarrow SH$	$k'(H), k'(S)$	(10)

With these equations assumptions of steady-state hydrogen-atom concentration leads to the expression

$$\frac{1}{G(H_2)_{max} - G(H_2)/m} = \frac{1}{G(H)} + \frac{k(RH)}{k'(S)G(H)}$$

($1/m$ stands for the reciprocal of the mole fraction of the *solvent;* that is, it corrects the observed yield for the fact that not all of the substance is solvent. For a 5-mole-percent solute $1/m$ = 1.05.)

For very efficient scavengers such as iodine (presumably), ferric iron or benzoquinone in the millimolar region, a plot of $1/\Delta G(H_2)$ (the term on the left) against $1/S$ should be linear. For scavengers effective only at concentrations greater than 1 m/o (mole per cent) (where $1/m$ and RH/S become significant, the corresponding plot is $1/\Delta G(H_2)$ against RH/S.

The indicated linear plots have been found for solutions of ferric ion and benzoquinone in methanol, ethanol, isopropanol, *t*-butyl alcohol, cyclohexanol, cyclohexane, ethyl ether, acetic acid, and ethyl acetate (*18*, *19*) and for solutions of benzene in methanol (*19*, *23*), for solutions of biphenyl and benzophenone in propanol-2 (*24*), and for solutions of methyl methacrylate in a number of hydrocarbons (*25*).

The zero intercept of such a plot is the value of $1/G(H)$, where H represents the scavengeable hydrogen; $G(H_2)_{max} - G(H)$ is then $G_m(H_2)$, H_2 being the unscavengeable hydrogen. Use of different scavengers should give the same intercept for the same solvent, and this has been found true in several cases (*19*, *24*, *25*). The slopes of these lines are measures of the competition between hydrogen abstraction from the solvent and hydrogen-atom addition to the scavenger (k/k'). For a given scavenger in several solvents, the values of this ratio indicate the ease of abstraction from the solvents and thus provide a pathway to effects of molecular structure, temperature, phase, LET and other variables upon this important aspect of radiation chemistry in liquids. Only a beginning has been made in obtaining data by this procedure (*18*, *24*, *25*).

Linearity of these plots does not prove that the mechanism is radical scavenging since from (a) the energy transfer mechanism, (b) the first four of the following equations and (c) a steady-state assumption for concentrations of R* and H, one can devise a similarly linear relationship between $G(H_2)$ and S (Eq. 19).

Equation	Rate	
$RH \rightarrow RH^*$	$G(^*)$	(11)
$RH^* + S \rightarrow RH + S^*$	$k_T k(RH^*)(S)$	(12)
$RH^* \rightarrow R + H$	$k_H(RH^*)$	(13)
$RH^* \rightarrow SS + H_2$	$k_m(RH^*)$	(14)
$H + RH \rightarrow H_2 + R$	$k_A(H)(RH)$	(15)

$$\frac{1}{G(H_2) - G(H_2)_{obs}/m} = \frac{1}{G^*}\left[1 + \left(\frac{k_H + k_m}{k_T}\right)\frac{1}{S}\right]$$

A nonlinear relation results only if both radical scavenging and energy scavenging are presumed to be about equally important.

Several conditions and consequences are essential for the simple kinetics of radical scavenging:

1. Neither hydrogen atoms nor molecular hydrogen can originate from these inefficient scavengers in appreciable quantity. This limits useful scavengers to substances like aromatic molecules such as benzene or benzoquinone. Thus the data from acetone-propanol-2 systems could not be thus treated (*17*), except in a very approximate manner.

2. The concentration of scavenger must remain about constant. Use of benzophenone as a scavenger for hydrogen atoms from propanol-2 was greatly complicated by an incidental side reac-

tion between the ketone and the carbinol that removed benzophenone from solution at a much greater rate than that of the hydrogen atom scavenging (*26*). Since methyl methacrylate can be polymerized very rapidly by radicals, it would be interesting to know initial and final methacrylate concentrations in Hardwick's experiments (*25*).

3. The scavenger should disappear from solution at a rate comparable with the number of radicals scavenged; for the experiments dealing with hydrogen atoms the destruction coefficient for the scavenger should be greater than that based on the decrease in $G(H_2)$ because the scavenger is presumably scavenging other radicals also. Existing measurements are not entirely reassuring on this point although in substantial agreement. $G(R)$—measured by the destruction of the scavenger—has been found larger than $G(H) + G(CH_3)$ (*18*). The destruction coefficient for anthracene in cyclohexane is about the same as the values of $G(R)$ measured by other means (*27*). We have found that the benzene destruction coefficient for 10% benzene-methanol solution was 3.6 molecules/100 ev [$G(H)$ was -3.4] and that for biphenyl in 2% biphenyl-propanol solutions $G = -1.07$ (*24*).

Much needs to be done to bring these numbers into quantitative agreement. Nevertheless these large values for disappearance of aromatic scavengers such as anthracene, benzene and biphenyl are much more consistent with radical scavenging than with energy transfer and thus should serve to distinguish the two kinetic treatments. It is apparent from this review that measurements of scavenger disappearance are important not only for knowing the mechanisms of scavenger action but also in learning about dose-rate effects, LET effects and other matters also.

Certain aspects of this sort of radical scavenging have barely been touched on. We have suggested that the carbonyl group of ketones can scavenge hydrogen atoms but not methyl radicals (*17*, *26*), and others have made comparisons of the relative scavenging efficiency of various scavengers (*19*, *24*, *25*). But systematic use of this technique to learn what structural features of a molecule determine scavenger efficiency has barely begun. The scavenging process should result in the formation of certain combination products, and the yield of these should increase with increase in the fraction of radicals scavenged; this matter is closely related to information about the kinds of radicals that a given scavenger can remove, and the relative efficiency of removal of each radical. Finally, study of these systems should enable much to be learned about activation energies of primary and secondary reactions in organic radiation chemistry.

Practically nothing is known about most of these matters. More work has been done in the benzene-cyclohexane system than in any other. Freeman has determined the yields of bicyclohexyl, cyclohexane and hydrogen in these systems (*28*) as functions of benzene concentrations. There is considerable debate about the mechanisms of product formation in the cyclohexane-benzene system, but it is our opinion that most of the data can be very well rationalized in the manner illustrated by Table 3.

TABLE 3—Mechanisms for Benzene-Cyclohexane System

	Process	*Product yield (molecules/100 ev)*	*Radical yield (radicals/100 ev)*	*Molecular yield (molecules/100 ev)*
C_6H_{12}	$C_6H_{11} + H$	$H_2 = 5.4$	4.2–4.6	0.8^{37}–1.2
C_6H_{12}	$C_6H_{10} + H_2$	$C_6H_{10} = 3.0$	—	0.6
$2C_6H_{11}$	$C_6H_{10} + C_6H_{12}$	3.0	2.4	—
$2C_6H_{11}$	$(C_6H_{11})_2$	1.4–1.5	1.4	—
Material balance				
	$H = 2 \times 4.2$		$= 8.4$	
	$C_6H_{11} = 2 \times 2.4 + 2 \times 1.4$		$= 7.6$	
	C_6H_{10}		$= 0.6$	
	H_2		$= 0.8$	

The effect of dissolved benzene on hydrogen yield is quantatively consistent (at benzene concentration $<10\%$) with hydrogen-atom scavenging; over this range indicated yields of hydrogen atoms and unscavengeable hydrogen are quite consistent with yields listed in Table 1 and with others (*24*). The data of Burton and Manion (*29*) can be recalculated to provide excellent agreement with the data of Freeman and that of Burr and Strong (*24*). If the data of Freeman for the effect of benzene on cyclohexene yield is recalculated to a pure cyclohexane basis, the curve becomes linear above 20% benzene (it can be calculated that 20% benzene also scavenges over 95% of the hydrogen atoms). The straight line presumably represents energy transfer from cyclohexane to benzene; the extrapolated molecular yield of cyclohexene at zero benzene content is 0.6 molecule/100 ev, which is in fair agreement with the calculated molecular yield of hydrogen. From Table 3 the material balance of cyclohexyl radical is obtained by balancing the best yields of cyclohexene and bicyclohexyl with indicated yield of hydrogen atoms and is pretty good although the persistent low numbers from cyclohexene and bicyclohexyl suggest that we do not yet know everything about this system.

Temperature dependence of the scavenging process is also in fair agreement with this mechanism (*31*). We have measured yields of hydrogen, cyclohexene, bicyclohexyl, and phenyl cyclohexane as functions of temperature (at 5–80°C, the whole liquid range) and of benzene concentration. We find that the competition between cyclohexane molecules and benzene molecules for hydrogen atoms is not measurably temperature dependent, and thus the relative values of $G(H)$ and $G(H_2)$ are also temperature independent. The formation of cyclohexene by the molecular process appears to be temperature independent, and the relative yields of bicyclohexyl and cyclohexene by radical-radical reaction also appear to be temperature independent. The lack of temperature effect in dissociation, recombination and disproportionation processes is not unexpected in view of the known very low or zero activation energies for such processes, but the lack of temperature effect on the competition of cyclohexene and benzene for hydrogen atoms is unexpected. It may perhaps be taken to mean that the 7–8-kcal/

mole difference in activation energies for Eqs. 9 and 10 is insignificant compared to the kinetic energies of the hydrogen atoms, that is, that these are the reactions of "hot" hydrogen atoms.

Some Contradictions

Tracer techniques, particularly with deuterium labeling, have enabled learning much about the mechanisms of organic radiolysis (*31*), and occasionally some unusual interpretations have resulted.

The principal areas of confusion occur when equimolar mixtures of a substance and its perdeutero analog (for example C_2H_6 and C_2D_6) are irradiated and the hydrogen formed from radiolysis of a saturated symmetrical hydrocarbon contains H_2, HD and D_2; since a unimolecular dissociation could produce only H_2 and D_2, the HD formed is a measure of bimolecular reactions such as hydrogen and deuterium abstraction. If hydrogen atoms are responsible for the HD formation, a scavenger should eliminate the HD, and indeed Dorfman did find that addition of ethylene to the ethane-ethane-d_6 mixture did prevent the formation of HD (*31*). Consequently one would not expect HD to be formed in the radiolysis of ethylene-ethylene-d_4 mixtures and it is not formed—apparently because ethylene serves as a self-scavenger.

But acetone, benzene, and biphenyl are all hydrogen-atom scavengers of efficiencies ranging from fair to good (measured by the kinetic treatment described above), and radiolysis of mixtures of these with the perdeutero analog produces large amounts of HD (*31*). It does not appear likely that this HD originates from hydrogen-atom reactions (HD yields from solutions of benzene-d_6 and cyclohexane (*32*) are not inconsistent with benzene as the origin of deuterium atoms—with a radiation yield of about 2–3 atoms/100 ev—which then react in a typical scavenging process) but must represent a complexity in the processes producing unscavengeable hydrogen. Some of the possible complexities have been pointed out (*33*). We have almost uncovered an interesting and pertinent situation in the radiolysis of methanol and deuterated methanols (*23*); the data are shown in Table 4. Benzene reduces the hydrogen yield from methanol as expected; we can calculate as above that the hydrogen-atom yield is 4.20 atoms/100 ev and that 10% benzene should scavenge about 84% of the scavengeable hydrogen atoms. If the HD which is produced from CH_3OD arises from hydrogen atoms, addition of 10% benzene should reduce the relative content of HD by about 84%. It can be seen from Table 4 that nothing of the sort occurs; the total amount of hydrogen decreases, but the HD content does not change nearly this much.

TABLE 4—Yields from CH_3OH and CH_3OD Solutions in Benzene

Substrate	*Benzene concentration (m/o)*	*Hydrogen yield (molecules/ 100 ev)*	$\%H_2$	$\%HD$	$\%D_2$	*Methane yield (molecules/ 100 ev)*	*Hydrogen-atom yield (atoms/ 100 ev)*
CH_3OH	0	5.32	100			0.37	
	4.80	2.00	100			0.169	
	10.0	1.59	100			0.145	4.20
CH_3OD	0	3.60	40.0	60.0	0	0.62	
	10.58	1.52	46.0	50.0	3	0.27	2.34*

* Assuming that $k_2/k_1 = 72$ for this solution as well as for solutions of benzene in methanol.

It is apparent that unscavengeable hydrogen originates not by a unimolecular mechanism but by something more complicated, and since this hydrogen is still an unequilibrated mixture, it seems probable that at least two processes are taking place; one produces HD and the other simply H_2. It is possible that a set of ion-molecule processes such as used by Dorfman and Sauer (*34*) would provide an effective correlation.

* * *

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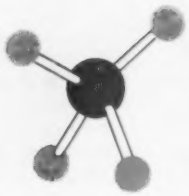


INTERMEDIATES IN LIQUIDS

Fast reaction techniques (such as pulse radiolysis) and sensitive detection methods (such as electron-spin resonance) make possible direct observation of reactive species and elementary processes

by LEON M. DORFMAN, *Argonne National Laboratory, Argonne, Illinois*

A FULL EMPIRICAL understanding of any chemical reaction requires three basic items of information. The first two involve a reliable identification of the transient chemical species formed and the elementary reactions in which they participate. The third is a quantitative determination of the absolute rate constants for these elementary reactions.

Direct observation is difficult because of the high reactivity of the intermediate species. The transients have a very short lifetime, attaining during a steady irradiation only a very low steady-state concentration. Direct detection is possible only through methods of unusually high sensitivity or by fast reaction techniques as in the method of pulse radiolysis.

Pulse radiolysis has become feasible within the past few years through the availability of electron accelerators which deliver a very short pulse of high energy electrons of extremely high intensity. Such a pulse creates an instantaneous concentration of transient species sufficiently high to permit detection by fast methods such as synchronized flash absorption spectroscopy. Observation of the decay of the transients by fast photoelectric recording provides direct information on the elementary processes.

Absorption Spectra

A number of transient species and rate processes have been observed in aqueous systems. Observations in both deaerated and oxygenated solutions of benzene in water have yielded new transient spectra (*1*). Previous investigations (*2, 3*) by conventional steady irradiations had shown the principal products to be diphenyl in the deaerated system and phenyl and hydrogen peroxide in the oxygenated system. The over-all chemistry has been interpreted in terms of hydroxyl radical attack upon the benzene

$$OH + C_6H_6 = C_6\dot{H}_5 + H_2O \quad (1)$$

and the subsequent reactions of the phenyl radical. It is not clear to what extent hydroxyl addition to the ring may occur. In the deaerated system the hydrogen atoms from the water must add to the benzene, but its fate then is not known.

Pulse radiolysis studies (*1*) have yielded a transient UV absorption spectra with a strong maximum at 3,120 A and a second bond extending to shorter wavelengths. Experiments show that the observed transient is not the C_6H_7 radical. The effect of chloride ion, which scavenges (*4*) hydroxyl radicals by charge exchange, establishes that OH is in fact the precursor of the observed transient. On the basis of extensive deductive reasoning relating to the chemical behavior the observed spectrum is most logically attributed to the phenyl radical $C_6\dot{H}_5$. This assignment is by no means unambiguous as the hydroxy cyclohexadienyl radical $HOC_6\dot{H}_6$ is also a possibility. A second spectrum obtained in oxygenated solution is attributed to the organic peroxy radical.

Transient absorption spectra have also been observed (*5*) following pulse radiolysis of aqueous solutions of inorganic compounds. With a dilute solution of potassium iodide in water, a broad band is observed at 3,700 A. This is probably an absorption band of the diiodide ion, I_2^-, which has been observed in flash photolysis (*6*). A dilute aqueous solution of potassium bromate yields a broad, very short-lived absorption at 3,600 A, with a half-life of about 10 μsec. This has been observed in flash photolysis (*7*), and is attributed to the bromate radical, BrO_3.

Pulse radiolysis of a number of benzyl compounds in various organic solvents (*5, 8*) has yielded the absorption spectrum of the benzyl radical. There are two bands, a strong band with a maximum at 3,171 A and a weaker band at 3,055 A. The assignment of this spectrum has been reliably established in flash photolysis (*9*). It has been observed in pulse radiolysis of many systems such as: benzyl chloride, benzyl alcohol and benzyl formate in cyclohexane, ethanol or glycerol. A transient absorption spectrum has been observed (*5*) in dilute solutions of 1,4-cyclohexadiene in cyclohexane, but no attempt has been made to assign this spectrum.

ESR Spectra in Liquids

The detection by ESR of molecular species and molecular fragments containing unpaired electrons has been applied extensively (*10, 11*) to irradiated systems. The high sensitivity of the method, along with the relatively unambiguous identification of the species, and the moderately accurate determination of concentration offer a considerable advantage. The application of the method to fast reaction measurement is rather more difficult, and to date the observation of very short-lived transients has been carried out only in static systems although dynamic measurements of radicals with lifetimes on the order of 1 sec have been reported (*12*).

Until recently the detection by ESR of highly reactive free radicals in irradiated systems was shown to be feasible only in rigid media. This experimental requirement was imposed on the observations because the restricted mobility of the radicals, limiting their recombination rate, was necessary for the attainment of detectable concentrations. Very recently, however, the ESR spectrum of the ethyl radical in irradiated liquid ethane has been reported (*13*). The

magnetic field used in these experiments was homogeneous to better than a few tenths of a gauss, and since the line widths observed in liquids are very small an extremely high sensitivity is attainable. The spectrum was observed during irradiation of liquid ethane at 135°K with 2.5-Mev electrons from a Van de Graaff accelerator. The spectrum consists of a quartet of triplets, indicating, as in similar work in rigid media (*11*), that the electron interacts with one group of three equivalent protons and with another group of three equivalent protons. This distribution has been interpreted (*11*) in terms of a hyperconjugated electronic structure. At an electron current of 0.1 μamp the steady-state radical concentration in liquid C_2H_6 was estimated to be 7×10^{-8}M. These observations have been extended (*14*) to a number of irradiated liquid hydrocarbons. The results may be summarized as

Radical observed	*Systems in which detected*
methyl	methane
ethyl	ethane
n-propyl	n-propane
isopropyl	n-propane, cyclopropane, 1% propylene in ethane
allyl	cyclopropane
t-butyl	1% isobutylene in ethane, neopentane, neohexane
cyclopentyl	cyclopentane
cyclohexyl	cyclohexane

The ESR spectrum of the cyclopentyl radical in liquid cyclopentane consists of two quintuplet sets, the indication being that the electron interacts with one proton and with a group of four equivalent protons.

Absolute Rate Constant

The pulse radiolysis technique lends itself to the direct observation of elementary processes and hence to the determination of absolute rate constants. The first such determination reported (*8*) for a pulse irradiated system was an investigation of the reactions of the benzyl radical in organic solvents. With benzyl chloride in ethanol, for example, the *G*-values for product formation are: dibenzyl = 0.62, 2 phenyl 1-methyl ethanol = 1.2, and stilbene = 0.03 molecules/100 ev; 2,3-butanediol was observed but not measured, and the *G*-value for benzyl chloride disappearance was 3.1 molecules/100 ev.

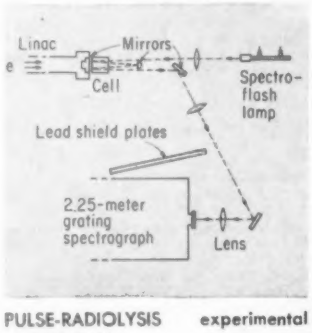
The rate process corresponding to the disappearance of the benzyl radical was observed in a more viscous solvent con-

Pulse Radiolysis Techniques

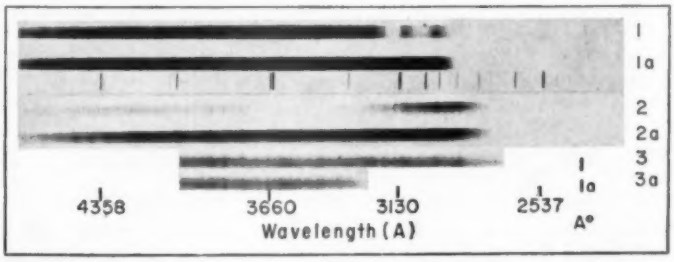
The electron accelerator in use at Argonne is an Arco Mark I linear accelerator. This linac delivers an electron pulse with a maximum duration of 5.5 μsec and an average current of 100 ma at 15 Mev (7–8 joules/pulse). In many systems this pulse will produce an instantaneous free-radical concentration in excess of 10^{-5}M. The experimental arrangement, which is detailed elsewhere (1), is shown in the sketch. The quartz irradiation cell is placed in front of the linac. A thin aluminum mirror on the outside of the front window of the cell serves to reflect the analyzing light beam. The electron beam enters through this window. The analyzing light beam enters collinearly with the electron beam, through the rear window. This analyzing light beam, after a four-fold reflection through the cell to increase the length of the light-absorption path, is directed to the slit of a 2.25-meter grating spectrograph.

To obtain absorption spectra of the transient species, a xenon flash lamp is used as the source of the analyzing light beam. This flash lamp, which provides a broad continuum with a pulse half-width of about 10 μsec is fired electronically at a pre-selected delay after the electron pulse. The spectra are recorded photographically. Once the region of spectral absorption of the transient species has been determined, direct observation of the rate processes is possible by fast photoelectric recording. For this purpose the spectroflash lamp is replaced by a steady source, usually a line source. The spectrograph is used as a monochromator, and light of a specific wavelength is directed to a photomultiplier. The transient signal from the photomultiplier is fed to a direct coupled current amplifier or to a cathode follower and the signal from this unit displayed on an oscilloscope where it is photographed. Rate curves may be obtained by observing the transient increase in absorption due to formation of a product as well as the transient decrease in ultraviolet absorption due to the disappearance of a transient species.

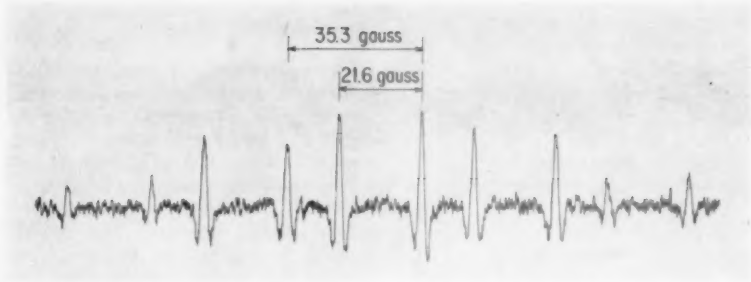
This experimental method represents a direct application to radiation chemistry of the well-developed techniques of flash-photolysis (19, 20). Since reaction is initiated by an electron pulse, it is well to bear in mind that the primary absorption of energy in dilute solutions is predominantly by the solvent molecules, as distinct from the absorption of light quanta by the solute molecules in flash photolysis. The technique has proved to be quite feasible for radiation-chemical studies and results on a number of systems, both aqueous and organic, have already been reported (1, 5, 8, 15). The pulse radiolysis techniques employed in other laboratories are not substantially different from the methods described above.



PULSE-RADIOLYSIS experimental arrangement



TRANSIENT U. V. absorption spectra in pulse radiolysis. 1 is benzyl radical in cyclohexane; 1a is blank; 2 is BrO_3 radical in water; 2a is blank; 3 is blank, 3a is phenyl radical in water. Any apparent fine structure in these spectra is characteristic of the spectroflash lamp and is not due to the absorbing species.



ELECTRON-SPIN RESONANCE spectrum of the cyclopentyl radical. The spectrum was observed in irradiated liquid cyclopentane at −80°C

sisting of 33% ethanol, 67% glycerol. The use of the more viscous solvent to reduce the reaction rate was necessitated by the fact that the first 25 μsec period after the pulse was blocked by a transient signal, presumably from the bremsstrahlung burst. The curve was found to fit a second-order rate law, consistent with the disappearance of the benzyl radical by radical-radical recombination reactions, and thus eliminated reaction of the benzyl radical with either ethanol or glycerol as a mode of product formation. From the rate curve and the product analyses in ethanol solution the disappearance of the benzyl radical was found to occur in two elementary reactions:

$$C_6H_5\dot{C}H_2 + C_6H_5\dot{C}H_2 = (C_6H_5CH_2)_2 \quad k_2 \quad (2)$$

and

$$C_6H_5\dot{C}H_2 + CH_3\dot{C}HOH = C_6H_5CH_2CHOH \quad k_3 \quad (3)$$

The rate constants for these reactions, at room temperature, in a solvent of 55-cp viscosity, were determined as: $k_2 = 4 \times 10^7$ liter/mole/sec and $k_3 = 2 \times 10^8$ liter/mole/sec. Comparison with theory indicates that both processes are diffusion-limited bimolecular reactions. There may be some uncertainty in assigning the decay of the transient to reactions 2 and 3 alone, since the observations were made in a solvent of which glycerol was the major constituent. It is likely, therefore, that a third radical, derived from the glycerol, may have been involved in the rate process.

In aqueous solutions of benzene (*1*) three separate rate processes have been observed. An absolute rate constant has been determined for one of these, the fast disappearance of the radical in oxygenated solution. Presumably the reaction

$$C_6\dot{H}_5 + O_2 = C_6H_5\dot{O}_2 \quad k_4 \quad (4)$$

is pseudo first order in oxygen-saturated solution with a bimolecular rate constant at 23°C of $k_4 = 5.0 \pm 0.5 \times 10^8$ liter/mole/sec.

The ESR observations also furnish information from which absolute rate constants may be deduced. From the known energy input and the measured steady-state radical concentration, with its observed dependence upon the square root of the current, a value (*13*) of $k_5 = 4 \times 10^9$ liter/mole/sec, at 135°K in liquid ethane is determined for the reaction:

$$C_2H_5 + C_2H_5 = C_4H_{10} \quad k_5 \quad (5)$$

The second-order disappearance, to which the rate constant refers, may also include disproportionation of the ethyl radicals as well as association. It seems unlikely, however, that the contribution of disproportionation will be large at 135°K.

Fast reactions, following pulse radiolysis, have been observed (*15*) in aerated water and in aqueous solutions of ceric sulfate and of ferrous ammonium sulfate. In aerated water, the decay of a transient absorption at 3,100 A, presumably due to the ferric ion, was observed over a period of several μsec. This work is quite preliminary and in neither case were the rate curves analyzed and assigned to specific elementary reactions.

Other Fast Reaction Methods

The observations summarized in the foregoing have all involved resolution times not much shorter than 1 μsec. Within this limitation only the secondary reactions are subject to direct observation. Resolution of times shorter than 10^{-7} sec would be necessary for direct observation of the primary processes. A subject of importance to which such fast measurements have been applied is that of energy transfer in multi-component liquid systems. Decay of luminescence in scintillator systems has been extensively studied. The limitations of space do not permit a survey of this work, but one recent advance in the measurement of fast luminescence decay times is particularly worthy of note. The use of the image converter tube in a repetitive time selection technique (*16*) has permitted a time resolution shorter than 10^{-9} sec. Studies (*17*) of nanosecond decay curves in benzene solutions of p-terphenyl have shown the occurrence of luminescence with two separate lifetimes. One of these is attributed to the excited state of the scintillator with a value of 2.2×10^{-9} sec. The other is attributed to a transferring state of the excited benzene molecule with a lifetime of 2×10^{-8} sec. The low pulse intensity, along with other experimental characteristics of this work, does not permit examination of selected narrow bands of the luminescence spectrum, but the importance of such observations relating to the primary process cannot be overemphasized.

The measurement of conductivity as a function of time has also been used (*18*) in the observation of fast reactions in irradiated solutions. The variation with time of the conductivity of aerated water submitted to pulsed x-irradiation has indicated the formation of ions with a lifetime greater than 0.1 sec. A preliminary analysis of the decay curves has led to the suggestion that the observed conductivity may be due to the radical-ion $\dot{O}_2^-$.

* * *

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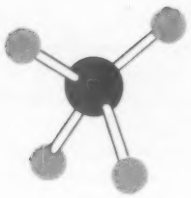

INTERMEDIATES IN SOLIDS

Intermediate species found in irradiated solid aliphatic hydrocarbons, alcohols, polyethylene, ice and nitrates support radiation-chemistry mechanisms. But yields can be measured with only ~50% accuracy now

by MAX S. MATHESON, *Argonne National Laboratory, Argonne, Illinois*

MANY CHEMICAL INTERMEDIATES ordinarily unstable in a liquid or a gas can be preserved and measured in a solid. To do so, the solid not only must prevent diffusion, but also must not react with the trapped species (at least at the temperature of measurement). Thus if we want to trap intermediates in compounds that are gaseous or liquid at ordinary temperatures we must use low temperatures (often as cold as liquid nitrogen or liquid helium).

Although it is important to the radiation chemist just to identify intermediates in such reactions, there also are theoretical reasons to study the "unstable" intermediates themselves. A practical reason would be the chance that such free radicals could serve as exotic high-energy fuels for rockets, but the maximum concentrations at saturation do not exceed a few tenths of a per cent (*1*).

Organic Compounds

Intermediates have been found in irradiated aliphatic hydrocarbons, alcohols and other organic compounds of small molecular weight.

Aliphatic hydrocarbons. The electron-spin resonances observed in normal aliphatic hydrocarbons after gamma irradiation can be attributed to radicals formed by the loss of a single hydrogen atom (*2–4*). It is surprising that despite the high energies available from secondary electrons, secondary hydrogens are lost in preference to the primary ones.

Where comparisons can be made, the radicals observed are those postulated as important in radiolysis of these compounds as gases or liquids at higher temperatures (*2*). We can see little C—C bond breaking in straight-chain hydrocarbons although the complex spectra of the branched hydrocarbons (neopentane, isobutane) suggest C—C rupture in these compounds; this difference agrees with usual radiation-chemistry studies. For ethylene, presumably a hydrogen atom adds to ethylene to give an ethyl radical; the fate of the other fragment is unknown.

Alcohols. Irradiated alcohols (especially methanol and ethanol) have been examined for intermediates (*2, 3, 5*). Conductivity in methanol during irradiation is proportional to the applied field and dose rate. Thus apparently the distance the average electron travels does not depend particularly on the type of trap formed during ionization—and many suitable traps are available. After irradiation, methanol (red-purple) has a broad visible absorption (peak ~ 5,200 A) and an ultraviolet absorption (beginning below 3,000 A) (*3*). There are two electron-spin-resonance spectra, a triplet and a singlet centered approximately on the triplet (*6*). Studies with deuterated compounds indicate $\cdot CH_2OH$ might cause the triplet. The singlet might be caused by an alcohol ion. Bleaching the purple color with visible light gives no photoconductivity even though 10^{19} trapped electrons could be detected. On the other hand bleaching this visible absorption removes the singlet electron-spin resonance and produces a triplet intensity correspondingly (*6*). Irradiation with ultraviolet light (~ 2,500 A) reduces the triplet (total spread 36 gauss) and increases the doublet correspondingly (129 gauss). The table shows that the radiation yield of spins in methanol is 5.5 spins/100 ev at 77°K (*3*); in liquid methanol G for ethylene glycol (½ of $\cdot CH_2OH$) is 3.1 and G for $\cdot CH_2OH$ by scavenger techniques is 2.7 (*7*).

To summarize, free electrons are present during irradiation by gamma rays, but the importance of the electron trapping process is not known. Two species with odd electrons are trapped. One, probably a precursor of the other, gives a singlet electron-spin resonance (no strong interaction between the electron and hydrogen atoms) and a strong visible absorption. The other species gives triplet resonance (two hydrogen atoms interacting equally with the odd electron) and apparently absorbs ultraviolet rays. In agreement with the electron-spin resonance and the product $(CH_2OH)_2$ obtained in liquid methanol at room temperature, this second species probably is $\cdot CH_2OH$. The radiation yields roughly agree for solid and liquid. Analogous studies have been made with ethanol.

Other organic compounds. Many other irradiated organic compounds have been examined for electron-spin resonance. For instance, the x-irradiation of single crystals of malonic acid (*8*) to give $\cdot CH(COOH)_2$ and of succinic acid (*9*) to give $(CO_2H)\text{-}\dot{C}HCH_2(COOH)$ has helped establish the theory of electron-spin resonance for aliphatic radicals. The resonances of many irradiated biological compounds (such as amino acids and proteins) have been studied in attempts

to identify their intermediates (*10–12*).

When the four monomers acrylonitrile, methacrylonitrile, methyl acrylate, or methyl methacrylate are x-irradiated at 77°K, the original resonance spectra are not those obtained when using hydroxyl radicals to attack the frozen monomers (OH from H_2O_2 and ultraviolet). When the irradiated monomers (except acrylonitrile) are warmed, the spectra change to those observed in irradiated polymers or for the occluded radicals in precipitated polymers (*13*). When they are melted, polymer is found.

Inorganic Compounds

Since water is an important compound in radiation chemistry, trapped intermediates in ice have been investigated thoroughly. The radiation chemistry of nitrates has also been studied (*14, 15*).

Water. Principally hydrogen atoms and hydroxyl radicals are invoked to explain the radiation chemistry of water. For aqueous systems, the electron-spin-resonance doublet due to hydrogen atoms first was observed in frozen aqueous solutions of sulfuric, phosphoric or perchloric acids gamma-irradiated at 77°K (*16*). The doublet observed has a splitting close to the atomic beam value (~507 gauss); substitution of heavy water for ordinary water gives the expected triplet for deuterium atoms. Hydrogen atoms, which are not trapped in pure ice at 77°K, have been observed in pure ice irradiated at 4.2°K (*17*); estimated yield was ~0.9 hydrogen atoms/100 ev. This is considerably less than the hydrogen-atom yield in neutral water at room temperature [estimated as $G(H) = 2.75$ (*18*)]. The hydrogen-atom concentration approached saturation at $\sim 8 \times 10^{-6}$ moles H/gm ice. In acid systems the hydrogen-atom yields depend on acid concentrations and (except for $HClO_4$ systems) on whether the samples are crystalline or glassy (*19*). The yields for molecular hydrogen measured after melting the samples correlate well with the hydrogen-atom yield measured by electron-spin resonance (except in pure ice where hydrogen atoms are not stable at 77°K). This indicates that most of the hydrogen atoms subsequently formed hydrogen molecules. The decay of hydrogen-atom concentration in acid systems is second order.

The first electron-spin resonance detected in pure ice gamma-irradiated at 77°K was interpreted erroneously (*20*); it probably is due partly to hydroxyl radicals (*21, 22*). The hydroxyl doublet in polycrystalline samples indicates an initial hydroxyl yield at 4.2°K of ~0.8 radicals/100 ev (*17*), as compared to 2.25 in neutral water at room temperature (*18*). The doublet decays (92–107°K) with an unexplained ½-order kinetics to leave an asymmetric broad line possibly due to HO_2 (*21*). The ion H_2O^+ might have been detected in single crystals irradiated at 77°K (*22*), but the fate of the electron is unknown. The saturation concentration was $\sim 1.8 \times 10^{-3}$ *M* for hydroxyl radical at 77°K (*21*). The doublet, here attributed to hydroxyl, also is thus observed both at 77 and 4.2°K (*17*). Recently further evidence has been presented for the hydroxyl identification and a poorly resolved 12-gauss doublet has been assigned to HO_2 (*23*).

Fluorescence (*24*) and thermoluminescence (*24, 25*) have been observed in ice x- or gamma-irradiated at 77°K. The efficiency ($\sim 10^{-4}$ quanta/100 ev) of fluorescence is low and that for thermoluminescence much lower; the fluorescence has been associated with cationic impurities (*24*). A broad absorption in irradiated ice with a maximum at 2,800 A also is found (*26*); it disappears with about the same temperature dependence as one of the thermoluminescence peaks (−155°C). We can speculate that this absorption is due to presence of hydroxyl radical.

To summarize, the principal radicals that explain the radiation chemistry of water have been found in irradiated ice, the hydrogen atom certainly, the hydroxyl radical probably. The radical yields in ice are comparable in magnitude but less than those observed in water. HO_2 probably has been observed (and possibly an ion).

Nitrates. Certain oxygenated inorganic salts [such as alkali-metal nitrates (*14, 15*), chlorates or bromates] under irradiation decompose readily to yield oxygen as one of the products; on the other hand, sulfates and carbonates are relatively stable. At room temperature, the final products of nitrate irradiation are NO_2^- and molecular oxygen trapped in the crystal with a yield in potassium nitrate of 1.47 molecules/100 ev at −110°C (*27*). The light absorption of sodium nitrate irradiated at −190°C or at room temperature indicates two species: (a) NO_2^- with an absorption band at 3,450 A and (b) color centers with an

Yields for Radicals in Irradiated Solids

Compound	*Radical suggested*	*Temperature (°K)*	*Radiation yield* (molecules/100 ev)*	*Ref.*
H_2O	H	4.2	0.9	*17*
H_2O	OH	4.2	0.8	*17*
H_2O	OH	77	0.6	*17*
H_2O (glass)	H	77	0	*59*
H_2O (crystal)	H	77	0	*19*
H_2O (0.2 mole fraction H_2SO_4)				
(glass)	H	77	1.69	*19*
(crystal)	H	77	~0.02	*19*
H_2O (0.8 mole fraction H_2SO_4)				
(glass)	H	77	~0.26	*19*
(crystal)	H	77	~0.2	*19*
Methane	$\cdot CH_3 + H$	4.2	3.8	*58*
Methanol	$\cdot CH_2OH$	77	5.5	*3*
Ethanol	$CH_3\dot{C}HOH$	77	8.3	*3*
Cyclohexane†				
quick freezing	Cyclohexyl	77	3–4	*13*
quick freezing, then anneal	Cyclohexyl	77	1.2	*13*
Cyclopentane†				
quick freezing	Cyclopentyl	77	2	*13*
quick freezing, then anneal	Cyclopentyl	77	0.3	*13*
Polyethylene (linear)	$—CH_2—\dot{C}H—CH_2—$ (mostly)	77	3	*38*

* Even with careful measurement of yield by electron-spin resonance, accuracy is probably no better than ±50%. † Yields indicate importance of crystal defects.

absorption band at 3,350 A (*28*). The color center might be caused by electrons trapped near NO_2^- (represented here as NO_2^{--}). Electron-spin resonance has been observed in irradiated sodium nitrate (*29*) and in potassium nitrate (*30*). In potassium nitrate four triplets and a singlet have been observed and identified tentatively as: (a) NO_2^{--} with associated ultraviolet absorption at 3,550 A (observed at 4 or 77°K); (b) NO_2, which requires longer irradiation for observation than NO_2^{--}; (c) NO_3^{--}, which is stable at 4°K but decays completely in a few days at 77°K; (d) NO radicals; and (e) O_2^-, which is probably the singlet. The N^{14} nucleus is responsible for the triplets, as is shown by work with N^{15}. The initial yield for radicals is ~2.2 at 77°K, and the radical concentration saturates at $\sim 4 \times 10^{20}$ spins/mole of potassium nitrate after irradiation to $\sim 4 \times 10^{22}$ ev/mole.

Organic Polymers

A number of irradiated polymers examined for induced electrical conductivity (*31*, *32–34*) and electron-spin resonance (*35*) have shown results that do not always agree completely (*36*). Even so, if we allow for the fact that apparently similar polymers might

Eight Ways to Detect Intermediates in Solids

Electron-spin resonance is the method used most (2–6, 8–13, 39–41). In favorable cases an intermediate can be identified positively with identification based either on theoretical or experimental results. (The number and spacing of the absorption peaks in electron-spin-resonance spectra will depend on the nuclear spins of the atoms in the radical near the free valence electron. For many radicals only the hydrogens contribute.) The method is sensitive; at room temperature it has an optimum sensitivity of $\sim 10^{13}$ total unpaired spins ($\sim 2 \times 10^{-8}$ molar for a sample of 0.1 cm^3) (42). But this method is limited to molecules with unpaired electrons (and triplet molecules might be more difficult to observe because of zero-field splitting).

Ultraviolet absorption spectroscopy is second in importance (41, 43–45). If it is present in sufficient concentration, we should be able to observe any intermediate with or without an unpaired electron having optical absorption that is not obscured by absorption in the matrix. With a high molecular extinction coefficient of 10^4 liters/mole/cm and absorption in an accessible region of the spectrum, the sensitivity is nearly as good as that of the electron-spin-resonance method. Intermediates can be metastable excited states of molecules or reactive fragments. Unfortunately, many important species (such as alkyl radicals) do not absorb strongly in accessible regions (46). Comparison with gas-phase spectra is important for identifying intermediates, but the broadening effects of the matrix on the spectrum might make identification difficult or impossible. Light scattering is often a serious problem for solids in the ultraviolet range, but is less serious in the infrared.

Infrared absorption can detect more intermediates, but the lower absorption coefficient in the infrared makes it less sensitive (47). Thus it has not detected unstable intermediates (such as radicals). Infrared has successfully followed double-bond concentration changes in polyethylene (48, 49), although these double bonds are not truly unstable intermediates.

Fluorescence, phosphorescence and thermoluminescence, as work on scintillators shows, can be more sensitive than the other methods. But they cannot be used with the many systems that do not emit light. Leach has photolyzed rigid solutions of benzyl derivatives and then used another light source to stimulate the emission spectra from products, including a spectrum identified as belonging to benzyl radicals (50); this method should be applicable to the irradiation of ϕCH_2X compounds (43). Light may be emitted during irradiation (thermoluminescence particularly is observed frequently after irradiation), but quantitative observations are rare. An exception is nitrogen, whose luminescence excited by ionizing radiation or other means has been studied thoroughly (51, 52). The spectra are complex and in part are due to impurities such as oxygen. Gamma-irradiated acetone gives thermoluminescence, presumably corresponding to the known phosphorescence of the triplet state (3); the trap depth is ~0.15 ev (bleaching acetone with light does not produce a detectable electric current). Other irradiated ketones also give glow curves.

Electrical conductivity methods are exceedingly sensitive in nonionic organic solids, and often provide the only data on charged species, especially electrons. In substances such as aliphatic hydrocarbons and alcohols neither electron-spin resonance nor light absorption has positively identified an ion. The small currents produced indicate that either the effective mobility or the number of charges is very low. Conductivity decays after irradiation, but can be increased again temporarily by heating. This indicates trapped electrons, but the currents are small. Conductivity has been observed during irradiation of methanol (53). Much conductivity work has been carried out on insulating plastics during and after irradiation (31–34).

X-ray diffraction effects require at least a 1% concentration of intermediates, so this method has been used only to determine whether the trapping medium is amorphous, polycrystalline or monocrystalline (54).

Differential thermal analysis can be applied to irradiated compounds such as ammonium perchlorate (55). But the method requires large concentrations of intermediates identifiable by other means.

Chemical methods can show that radicals are trapped in solid monomers. For instance, tetraethylene glycol diacrylate irradiated at low temperatures rapidly (sometimes violently) polymerizes when warmed (56). Graft copolymerization (in which an irradiated polymer induces another monomer to polymerize upon or in it) also indicates trapped radicals (57). Finally we can make the usual chemical studies of products and kinetics to deduce the presence and nature of intermediates.

differ in crystallinity, impurities, etc., considerable progress has been made.

The conductivity induced in plastics by x-rays has been explained by a theory analogous to that for semiconductors (*31*). The induced current i_x varies as R^{Δ}, where R is the dose rate. The constant $\Delta \approx 1$ if the electron traps are distributed uniformly with the trap-depth (energy). For smaller values of Δ (approaching 0.5 as a limit), such as 0.8 found for polyethylene, we can deduce a trap distribution in which the number of traps decreases exponentially with depth. Then we can calculate various parameters. Thus, assuming 1 cm²/volt-sec (*33*) for the mobility of an electron in polyethylene we can find only 600 free electrons/cm³ for a dose of 8 r/min at 20°C at steady state (*37*). On the other hand 10^{15} electrons/cm³ have been trapped and a corresponding number of holes or ions exist in the polymer. This would be 10^{14} ions in a 0.1-cm³ sample, which is within the range of sensitivity of electron-spin resonance if other factors do not prevent observation.

Electron-spin resonance as a function of various factors has been studied carefully and a consistent interpretation offered (*38*). At low doses (40 Mr) at 25°C and −196°C, a six-line and five-line spectra are found. The same total number of radicals are produced at each temperature, but at room temperature the six-line spectrum decays to zero in five days. The six-line spectrum is attributed to —CH_2—$\dot{C}H$—CH_2— and the five-line (longer-lived) to —CH_2—CH_2·$\cdot CH_2$—CH_2—. A hydrogen atom is produced with the first —CH_2—$\dot{C}H$—CH_2— of a pair and this attacks a neighboring chain to produce the second radical of the pair. These pairs of —CH_2—$\dot{C}H$—CH_2— radicals exist close to each other and account for the crosslinking. If we assume that the crosslinking yield is equal to the difference between the measured hydrogen-molecule yield and the transvinylene yield, we find that the crosslinking yield is 2.0 molecules/100 ev and is about half the yield for the six-line radical as expected. With greater doses, first the six-line spectrum, then the five-line, go through a maximum intensity, while a broad singlet appears and grows in intensity. The singlet is attributed to conjugated radicals such as —$\dot{C}H$—$(CH{=}CH)_n$—.

* * *

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Experiment versus Theory

Even after the difficulties of identification have been overcome, be cautious when trying to relate observed intermediates to the radiation chemistry of an irradiated compound because

- they might be intermediates in a minor side reaction (measurement of a radiation yield for the species might eliminate this uncertainty)
- the course of the reaction in a cold solid might differ from that in the warmer fluid (for instance, ionic polymerization, which is favored at low temperatures)
- the position of the intermediate in the main-reaction sequence often is not known (that is, it might be formed in a secondary reaction by the attack of a primary product; thus, as in hydrocarbons, "hot" hydrogen atoms might attack the parent compound to form the species observed).

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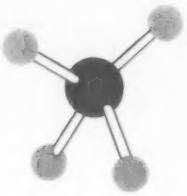


HOT-ATOM REACTIONS

Atoms endowed with abnormally high energies collide with molecules to produce chemical reactions not possible when the same chemical species react with normal thermal energies

by JOHN E. WILLARD, *University of Wisconsin, Madison, Wisconsin*

HOT ATOMS—atoms with electronic-excitation or kinetic energies much in excess of thermal equilibrium values—are frequently produced in the irradiation of matter by particles or photons (see figure). These highly activated atoms may participate in chemical reactions that are forbidden to the same species at more usual energies. Such "hot" reactions

- yield products not formed by thermal reactions
- are temperature independent
- may be eliminated by inert additives that remove the kinetic, vibrational or electronic energy of the excited species before it undergoes reactive collisions
- are not affected by low concentrations of reactive additives that serve as scavengers for thermalized free radicals

These observations (*1–10*) indicate that the hot atom may form a new substance by replacing an atom or group and taking its place in the original molecule in a single step process. For example a hot tritium atom in a methane gas atmosphere can interact to produce the compound CH_3T through the reaction $T + CH_4 \rightarrow CH_3T + H$.

Chemical reactions between an atom and a molecule in thermal equilibrium with the environment are in general limited to the process that requires the least energy of activation. An atom with higher energy can often participate in a completely different reaction with the same type of molecule. The hot-atom chemist would like to study the variation in chemical products with variation in energy of the reacting atom over a wide range of energies above thermal energies. With respect to variation of products with energy hot-atom chemical reactions are similar to nuclear reactions between a bombarding particle and a target nucleus; for example, in the bombardment of magnesium with protons as the energy of the proton is increased the predominant nuclear products change.

Hot-Atom Activation

Hot reactions have been most commonly observed through activation by ultraviolet radiation, ionizing radiation, and nuclear transformations (see figure). In studying the reaction probability as a function of energy, monochromatic ultraviolet radiation is superior to the other means of activation because the energy of the hot species is well known, given suitable spectroscopic information. With ultraviolet radiation however, the number of hot species and the energy range over which they can be produced is limited by the absorption spectra and conservation of momentum during bond rupture.

Ionizing radiation is much less selective. It will activate any compound and usually produces a variety of excited states.

Hot-atom phenomena, however, have been most extensively studied with activation by nuclear transformations. In fact the term "hot-atom chemistry" is often used synonymously with "chemical effects of nuclear transformations."

All nuclear transformations yield products that have abnormally large kinetic energy or electrical charge or both. The energy of an atom produced by nuclear transformations is usually great compared to an atom activated by ultraviolet radiation (2,000A = 2.3 ev) or ionizing radiation (common ionization potentials are about 10 ev). For example an iodine atom formed by the $I^{127}(n,\gamma)I^{128}$ reaction (with the emission of a 6-Mev gamma ray) will have a recoil kinetic energy of about 150 ev while a C^{14} atom formed by the emission of a proton in the $N^{14}(n,p)C^{14}$ reaction has a recoil energy of about 6×10^5 ev. Other examples are given in the table.

In each instance the recoil atom is made radioactive by the same process that gives it high energy. As a consequence it is possible to distinguish the atoms born with high energy from the others in the system and to study their chemical fates as functions of variables such as phase, temperature and composition of the medium. Because of the sensitivity of radioactivity detection the fraction of starting materials that must be converted to labeled molecules in studies of this kind can be extremely small. Compounds present as only a few million molecules can be separated by gas chromatography and detected as substantial peaks on a chart recorder if they are

labeled with recoil atoms that have a half-life of an hour or so (*11*).

Gas-Phase Reactions

Early investigations of reactions activated by nuclear processes in the gas phase gave information that radiative neutron capture by the halogen in compounds such as C_2H_5Br nearly always results in rupture of the carbon-halogen bond. In these studies the atom eliminated usually reacted to form a molecule of hydrogen halide or free halogen; it did not reenter organic combination to an appreciable extent.

Added significance was given to gas-phase studies by the discovery that when iodine atoms are activated by the $I^{127}(n,\gamma)I^{128}$ process in methane, 50% formed CH_3I by a unique hot displacement process ($I + CH_4 \rightarrow CH_3I + H$) (*12*). Investigations soon showed that similar reactions occur for chlorine and bromine atoms activated by radiative capture (*13*), the efficiency of the atom for the displacement reaction depending on both the particular halogen involved and the target compound.

Carrier techniques and, most importantly, the application of gas chromatography to the separation of traces of radioactive compounds (*11*) have revealed that hot halogen atoms from the n,γ process in the gas phase could displace not only hydrogen atoms but also radicals and other halogen atoms from hydrocarbons; thus, for example, the neutron irradiation of n-C_3H_7Cl (*22*) produces more than 14 different organic chlorides containing Cl^{38}. Further investigation (*14*) of the $I^{127}(n,\gamma)I^{128}$ process in methane showed that the organic yield falls in the presence of inert gases that moderate the recoil I^{128} but that the yield is much more sensitive to additives whose ionization potential is lower than that of I^+ and, hence, can neutralize it.

Recently Rack and Gordus (*15, 16*) have extrapolated the organic yields of the $I^{127}(n,\gamma)I^{128}$ reaction in CH_4 with various additives to 100 m/0 additive. They divide the additives into three classes: those that reduce the yield from the normal 54% value to 36%, those that reduce it to 11% and those that reduce it to 0. From these results and spectroscopic data the authors conclude that 18% of the I^{128} atoms react to form CH_3I^{128} by a mechanism that is kinetic-energy dependent, 25% react as translationally thermalized but electronically excited $I^+(^1D_2)$ ions and 11% react as I^+ ions in lower states than $I^+(^1D_2)$.

Recoil tritium atoms produced by the $He^3(n,p)H^3$ reaction in the gas phase are able, like recoil halogen atoms, to displace hydrogen from methane and to displace other groups from more complex molecules (*2, 3, 17*). As a controlled source of hot atoms for the study of hot-atom reactions recoil tritium atoms have the advantage over halogen atoms that delayed gamma emission with internal conversion, which can charge the atom after it has been neutralized and moderated, cannot occur. Whereas the frequency and decay rates of internal conversions in the halogens are not known in detail, the recoil tritium species are probably always neutral atoms by the time they have been slowed down to the energy range of 10 ev, in which stable reaction products are formed (*18*).

Estrup and Wolfgang (*19*) have developed a mathematical model of hot-atom reactions in the gas phase to calculate the total probability that a hot atom will react before losing its energy; the probability is expressed in terms of the average collisional energy loss and the efficiency of reaction on collision. The theory is in good agreement with the observed effects of moderators on the reactions of hot tritium atoms with methane (*20*) and has proved useful in the analysis of the reactive species responsible for the reactions of recoil iodine and bromine with methane (*15*).

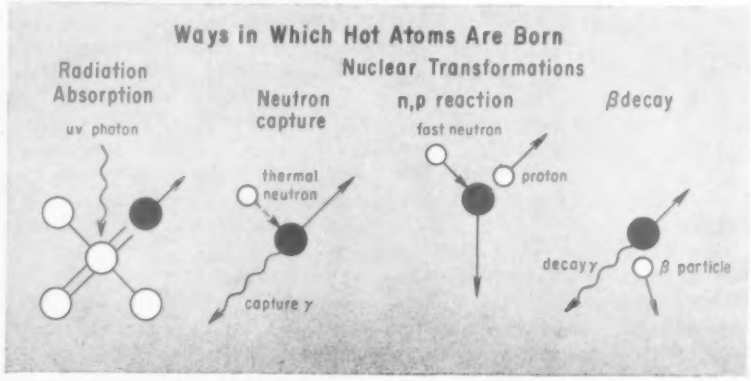
Apparently hot-atom displacement reactions do not involve intermediate steps in which the energy is distributed among the various bonds of the molecule. Rather the hot atom displaces a specific atom or group (*2, 3*).

In fact hydrogen displacement from gaseous optically active sec-butyl alcohol (*2*) or from solid glucose and alanine (*21*) by hot tritium atoms can take place without change in configuration around the asymetric carbon atoms. These observations are consistent with the concept (*2*) that the particular reaction undergone by a hot tritium atom depends critically on its point of attack—hydrogen abstraction is most likely if the collision is head on with a hydrogen atom; if the collision is with a carbon atom, displacement is most likely and occurs within the period of one vibration.

When a hot tritium displaces a hydrogen atom or a radical from a molecule, much of the energy is presumably carried off by the departing species, but some remains with the new molecule. This was demonstrated in the investigation of reactions of hot tritium atoms with cyclopropane by Lee, Musgrave and Rowland (*3*). They observed an increase in the yield of tritiated cyclopropane and decrease in the yield of propylene with increase in pressure, which can be accounted for by competition between collisional deactivation and decomposition. Decomposition of excited molecules also appears necessary to account for some of the reaction products of hot halogen atoms such as the formation of vinyl chloride from propyl chloride

$$(Cl^{38} + C_3H_7Cl \rightarrow CH_3 + C_2H_4ClCl^{38*}$$
$$C_2H_4ClCl^{38*} \rightarrow C_2H_3Cl^{38} + HCl)\ (22).$$

As the fragmentation patterns of the excited molecules formed by hot displacement reactions become better



ENERGY-TRANSFER PROCESSES that give rise to hot atoms (black spheres) include four shown in schematic diagrams above

Some Nuclear Transformations That Produce Hot Atoms

Initial nuclide	*Process*	*Product nuclide*	*Half-life*	*Approx. maximum recoil energy (ev)**
I^{127}	n,γ	I^{128}	25 min	150
Br^{81}	n,γ	Br^{82}	36 hr	230
Cl^{37}	n,γ	Cl^{38}	37 min	510
N^{14}	n,p	C^{14}	5,600 yr	6×10^5
Li^6	n,α	H^3	12 yr	4.7×10^5
He^3	n,p	H^3	12 yr	2×10^6
Br^{80m}	I.T.	Br^{80}	18 min	0

* Assuming one 6 Mev gamma ray in the n,γ reactions.

known they may be found to yield labeled hot radicals useful in the study of hot-radical reactions.

Lee, Musgrave and Rowland have discovered that hot recoil tritium atoms show a preference by a factor of about 1.5 for reaction with H_2 to form HT as compared to reaction with D_2 to form DT (*23*). A similar preference for the abstraction of hydrogen atoms rather than deuterium atoms is found when the recoil atoms are produced in a mixture of CH_4 and CD_4, or in CH_2D_2 (*24*). Further investigation of these systems should yield significant information on factors that control reaction paths at energies in the range of a few electron volts above usual activation energies.

Ultraviolet radiation. Whereas the energy of tritium atoms produced from the $He^3(n,p)H^3$ reaction is so large (0.2 Mev) that they must be moderated before they can enter stable combination, photolysis of HI, DI, or TI with 2537- or 1849-A ultraviolet radiation will produce hydrogen, or deuterium or tritium atoms with 1.8 or 3.6 ev.

In gaseous mixtures of iodine molecules and hydrogen-iodide molecules the 1.8-ev hydrogen atoms show a higher ratio of reaction with hydrogen iodide relative to iodine molecules than do thermal hydrogen atoms (*25*). Hydrogen atoms of 3.6 ev (84 kcal/mole) have energy in excess of the bond energy of hydrogen iodide (70 kcal/mole), and are able to induce the reaction $H + HI \rightarrow H + H + I$ (*26*).

This is analogous to displacement of hydrogen from methane by a recoil tritium atom ($T + CH_4 \rightarrow CH_3T + H$) (*2, 17*), except that the hydrogen iodide does not have sufficient vibrational modes to hold the residual energy and so decomposes. Hydrogen atoms of 1.8 ev seem to show less than 5% (if any) hot reaction with methane to abstract or displace hydrogen (*27*) while more than 50% of the recoil atoms from the $He^3(n,p)H^3$ process undergo such a reaction (*17, 18*). Similar tests with the 3.6 ev atoms produced from tritium iodide or deuterium iodide by 1849-A radiation will be significant.

Photochemical activation has been used to produce hot CH_3 radicals and hot iodine molecules. The methyl radicals produced from methyl iodide by 2537- or 1849-A radiation, for example, abstract hydrogen from methyl iodide with quantum yields of about 3×10^{-3} and 3×10^{-2} atoms/photon for the two wavelengths. Moderators show that much of the radical energy at 1849 A is vibrational rather than kinetic (*28*).

Isomeric transition and beta decay. Finally there are the fundamental studies of Wexler (*29*) and of Snell (*30*) and co-workers on the primary products formed when atoms in molecules undergo beta decay or isomeric transition. For example, Wexler, with a specially designed mass spectrograph, has measured the spectrum of positively charged fragments produced when Br^{80m} in methyl bromide (CH_3Br) undergoes isomeric transition in the gas phase. He observed charged states of atomic bromine from Br^+ to Br^{+13} with a maximum at Br^{+7}. Other fragments included CH_3Br^+, CH_3^+, CH_2^+, C^+, C^{++}, C^{+++}, H_2^+ and H^+.

Liquid-Phase Reactions

Neutral hot atoms or radicals of only a few electron volts energy when produced in the liquid state by photochemical dissociation engage (as may be expected) in reactions similar to those in the gas phase. For example in experiments on the photolysis of hydrogen iodide in deuterated *n*-hexane or 3-methylpentane solutions, the 1.8-ev hydrogen atoms react to abstract deuterium from the solvent with a quantum yield of 0.2, which is independent of temperature from $-25°C$ to $-150°C$ (*30b*).

In contrast with photolytic activation, nuclear activation typically produces atoms with much higher kinetic energy and with high positive charge. Dissipation of the kinetic energy and neutralization of the charge within a small volume element of the solution must produce high concentrations of radicals, ions and excited molecules in the region where the tagged atom slows down to energies at which it can enter stable combination. The probability that the atom will enter stable combination by reacting with these species is much greater in the liquid than it is in the gas. In the gas the active species are distributed through a greater volume; caging effects are absent, and diffusion is relatively rapid. This is illustrated by the fact that the organic yields from activation of the halogen by radiative neutron capture in ethyl iodide and ethyl bromide are both about 1% in the gas phase (*9, 12*) compared to 40% and 32% in the pure liquids (*31*).

In the neutron irradiation of the liquid alkyl halides some of the recoil Br^{82} and I^{128} atoms escape immediate combination with the fragments they have produced and diffuse in thermal equilibrium with the solvent until such a fragment is encountered. Thus the organic yields of the liquid alkyl bromides and iodides decrease some 20% with the addition of only 10^{-3} mole fraction of free halogen (*31*), the latter scavenges the diffusing radicals and labeled halogen atoms, and so prevents them from reacting with each other. Scavengers cause no decrease in the organic yield of alkyl chlorides because the activation energy for hydrogen abstraction by the diffusing thermal chlorine atoms is so low that hydrogen-chloride formation competes effectively with diffusive combination with radicals (*13*). Evidence as to the identity of the diffusing radicals in some systems has been obtained by comparing the spectrum of products containing radiohalogen for experiments with and without added scavenger (*32*).

Of significance is the fact that the organic yields for the $(n,2n)$, (d,p), (γ,n) and (n,γ) processes of iodine in the liquid alkyl iodides are indistinguishable (*33, 34*). For the first three processes, in which particles are emitted, the recoil energies are of the order of 100,000 ev while for the (n,γ) process they are of the order of 100 ev. Equal organic yields for the $(n,2n)$ and (n,γ) processes have also occurred in the solid phases of several alkyl iodides and the product distributions for the two processes in liquid ethyl iodide are similar (*34*). Likewise the product distribution of Br^{80} atoms formed by the $Br^{80m} \rightarrow Br^{80}$ process in

a variety of media is identical or very similar to that formed by the (n,γ) process, including an instance in which some twenty products are formed (*11*). The Br^{80} atoms produced by the isomeric transition have high nuclear charge and essentially no recoil energy from the weak gamma-ray and electrons emitted, while the (n,γ) process produces bromine atoms with both charge and recoil energy. These and other similar observations that nuclides activated by drastically different nuclear processes can give the same organic yield and same distribution of products suggest that a decisive factor in the reactivity in all cases may be charge neutralization occurring near the end of the recoil atom track.

Metastable nuclear states may undergo internal conversion to produce charge on the atom after it has lost part or all of its recoil energy. The charge generated on a Br^{80} atom following isomeric transition spreads over the molecule and can yield fragments with several electron volts of kinetic energy in the gas phase. It is not clear, however, that this effect should be as large in the liquid phase where the electrons may be acquired somewhat symmetrically from the surrounding molecules.

A yet unexplained phenomenon is the fact that all alkyl chlorides give the same organic yield in the liquid phase regardless of the alkyl chain length or of concentration when dissolved in liquid hydrocarbons (*13*). The organic yield in these systems is thus independent of the momentum-transfer characteristics of the system and cannot be a result of the kinetic energy with which the Cl^{38} atom is born.

As indicated by the examples given above, and in a recent review of chemical effects of nuclear transformations of halogen atoms in organic media (*35*), the chemical properties of alkyl halides and the radioactive half-lives and cross sections for nuclear reactions of the halogens make them particularly suitable for studies of the mechanisms through which nuclear transformations produce chemical effects. A recent review by Wolf (*1*) summarizes the extensive investigations made of the products of the $N^{14}(n,p)C^{14}$ reaction in a number of media; it is notable that the distribution of the C^{14} atoms in the new molecules which they form is usually neither highly specific nor completely random.

Tritium-recoil reactions in the liquid phase have received relatively little attention because the Li^6 and He^3 from which they are generated do not have conveniently soluble compounds.

Solid-State Reactions

Among the least understood phenomena of hot-atom chemistry is the effect of changing from the liquid to the solid phase on product yields in organic systems (*6*) activated by radiative neutron capture. Total organic yields are sometimes the same in the solid as the liquid, sometimes higher and sometimes lower. Yields of individual products relative to each other sometimes change and sometimes remain the same.

A number of investigations of solid-state hot-atom reactions have dealt with the fate of magnesium, chromium arsenic, tin, bismuth the halogens and other elements in their inorganic salts following activation by radiative neutron capture, annealing at different times and temperatures, and dissolution in different media. This work is presented in detail in a recent review article by Harbottle and Sutin (*5*) which includes extensive references to the original papers.

De Maine, Maddock and Taugbol (*36*) have observed that the organic yield of bromine from hexabromoethane (C_2Br_6) irradiated with neutrons at room temperature is a function of the time and temperature at which the solid stands before dissolution. Further experiments (*37*) indicate that this annealing of the Br^{82}, which increases the organic yield, is strongly dependent on the amount of gamma radiation which the crystal has received. At low gamma doses some annealing occurs even on heating to 100°C. Higher gamma doses administered either during, after, or before the neutron irradiation lead to greater annealing on heating, indicating interaction between gamma produced imperfections in the crystal and recoil Br^{82} atoms in metastable positions.

* * *

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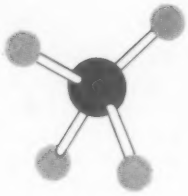

POLYMERIZATION

The field of radiation chemistry with commercial applications now is polymer chemistry. Advances with radiation-initiated polymers indicate that they form by free-radical and ionic mechanisms

by ADOLPHE CHAPIRO, *Centre National de la Recherche Scientifique, Bellevue, France*

IONIZING RADIATIONS have played an ever-expanding role in high-polymer chemistry in the last decade (*3–7*). The steadily growing interest of both polymer and radiation chemists in this field has been spurred on by their discovery of ways for making new plastic materials that have improved properties as well as manufacturing costs competitive with conventional methods.

The earliest discovery that attracted the interest of industrialists was the disclosure that thermoplastic polymers such as polyethylene become crosslinked by irradiation. These vulcanized materials exhibit new properties—better resistance to heat and chemical action and improved mechanical strength (*1*). By 1955 it was found that radiations are particularly suitable for preparing graft copolymers—polymers composed of two or more chemically different polymeric parts (*2*). Since graft copolymers are equivalent in the field of high polymers to alloys in metallurgy, this development opens an immense range of new potential uses for polymeric materials. The latest developments include polymerization of monomers at very low temperatures and crosslinking of polymers that normally degrade under irradiation. In the latter method, crosslinking is accomplished by adding solvents.

Since 1957 advances in uses of radiations in polymer chemistry have taken place in a variety of fields. Radiation-initiated polymerizations, for example, were in most cases reported to proceed by free-radical mechanisms (*3, 5*). Recent studies, however, have shown that under certain experimental conditions, radiation can also initiate ionic polymerizations. In addition, polymerizations can occur when solid monomers—sometimes frozen to very low temperatures—are irradiated.

Other advances in the past four years have occurred in radiolysis of solid polymers and polymers in solution and radiation-initiated grafting.

Free-Radical Polymerizations

At ordinary temperatures irradiation of most conventional vinyl monomers, either in bulk or in solution, leads to polymerizations that have the well known kinetic features of free-radical reactions (*3, 5*). The over-all reaction rate is governed by the following equation, verified by experiments with various monomers:

$$R = \frac{k_p}{k_t^{1/2}} R_i^{1/2}[M]$$

(k_p and k_t are rate constants for chain propagation and termination, respectively; R_i is formation rate of free radicals (rate of initiation) and $[M]$ is monomer concentration.) Thus the over-all reaction rate is usually proportional to the square root of the radiation dose rate over a broad range; the over-all activation energy equals the difference of the activation energies for propagation and termination, respectively, $(E_p - E_t/2)$. During the reaction free radicals are probably formed in dissociation of excited molecules that result either from direct interaction with ionizing particles or from ion neutralization.

Free-radical yields of a number of monomers have been derived from the kinetics of radiation polymerization and from studies with radical scavengers. Typical radiation yields for these monomers are listed in Table 1.

If a polymer precipitates in the reaction medium, noticeable deviations from conventional kinetics occur. Such behavior takes place in bulk polymerization of acrylonitrile, vinyl chloride, chlorotrifluoroethylene and

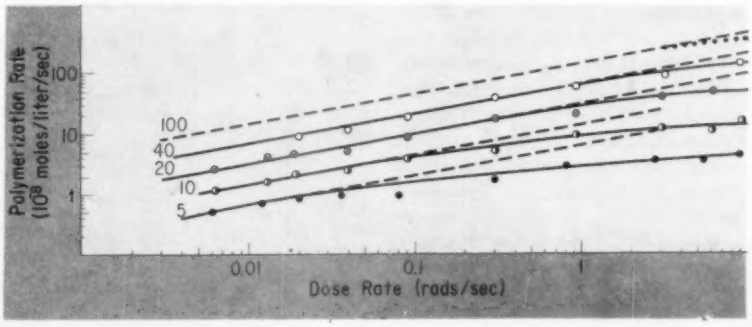

FIG. 1. STYRENE POLYMERIZATION rate against radiation dose rate for monomer solutions in toluene at different concentrations shows that critical dose rate at which deviation from square root relation (dotted line) occurs drops as concentration decreases

ethylene as well as in solution polymerization of styrene in alcohols. Since similar deviations from normal kinetic behavior are found with conventional sources of free radicals, this effect is not due to radiation-chemical events (*5, 7*).

Solution polymerization in homogeneous media is used for studying radiolysis of binary mixtures of organic compounds. In the most simple situation—when secondary processes can be ignored—one can determine the radiation yield of radicals with this method. In many cases, however, the production rates of radicals from monomers and solvents are not additive. Such effects are usually attributed to energy-transfer processes involving primary excited species (*8*). In studies of this kind, the monomer is in fact used as a free-radical scavenger. Therefore the method is only valid if the monomer efficiently competes with radical-radical interactions. While this condition is satisfied in radiolysis of pure monomers at reasonably small dose rates, it no longer holds above a critical dose rate, the value of which steadily decreases as the monomer is diluted in a solvent. Figure 1 illustrates this effect since the critical dose rate at which deviation from the square-root relationship occurs steadily drops as the monomer concentration decreases. Such an ideal behavior is not met, however, in all systems (*9*).

By measuring the radiolytic dissociation of various peroxides (*10, 11*) and radiation-induced luminescence (*12*), energy-transfer processes in vinyl-monomer systems have been investigated. Special attention has also been focused on radiation polymerization of some less common monomers including acroleine (*13*), vinyl-2-ethyl hexoate (*14*), alkyl-vinyl ethers (*15, 16*) and α-methylstyrene (*17–19*). Until recently we believed that the last two monomer groups polymerize exclusively by ionic mechanisms. Evidence now indicates, however, that the radiation-initiated reaction partly involves conventional free radicals. Because radiation polymerization of α-methylstryene is inhibited by water, however, there is probably also an ionic contribution to the process (*19*).

In the radiation-initiated polymerization and telomerization of ethylene (*20*), various monomers have been polymerized in emulsion (*21, 22*) and in suspension (*23*). By irradiating monomers in urea and thiourea-canal complexes one gets stereospecific polymerizations (*24*); it is questionable, however, whether this latter reaction is actually limited to a free-radical mechanism.

TABLE 1—Free-Radical Yields of Monomers (*7*)*

Monomer	*Method of derivation*	*Yield (radicals/100 ev)*
Styrene	Kinetics	0.69
	DPPH†	0.66
Methyl methacrylate	Kinetics	11.5
	DPPH	6.1
Methyl acrylate	Kinetics	(15.0)
	DPPH	6.3
Vinyl acetate	Kinetics	12.0
	DPPH	9.6
Acrylonitrile	Kinetics	5.6
	DPPH	5.0
Ethylene	Kinetics	4.0
Isobutylene	DPPH	3.9
	$FeCl_3$	3.0

* Derived from polymerization kinetics and studies with free-radical scavengers.
† Diphenylpicrylhydrazyl.

Ionic Polymerizations

Recent investigations in ionic polymerizations have been made with isobutylene and styrene among other monomers.

Polymerization of isobutylene takes place when the liquid monomer is irradiated at −78°C (*25–29*). Although this reaction is inhibited by oxygen and benzoquinone—typical free radical scavengers—it undoubtedly occurs by an ionic mechanism since this particular monomer polymerizes only to a high-molecular-weight polymer when treated with cationic catalysts. Moreover even in the presence of photosensitizers, photolysis of the monomer at −78°C does not lead to any appreciable amount of polymer (*27, 28*). In addition, diphenylpicrylhydrazyl (DPPH) does not affect the polymerization rate although the radicals formed reacted with this scavenger as a yield corresponding to $G(R) = 3.9$ (*27*) (see Table 1).

In radiation polymerization of isobutylene, the reaction rate is directly proportional to dose rate over a very broad range and the activation energy is −2.5 kcal/mole. Since at large doses both the rate and the molecular weight of the polymer steadily decrease, one assumes that an inhibitor, presumably diisobutylene, forms. The radiation yield of initiation, derived from initial rates and molecular weights, is $G(\text{active centers}) = 0.15–0.30$. Since addition of various inorganic materials noticeably increases the rate without affecting molecular weights, one assumes such additives increase the yield of active centers (*30*).

If one studies copolymerization of isobutylene with vinylidene chloride and styrene one sees further evidence that the reaction mechanism gradually changes from a free-radical to a cationic process as the reaction temperature decreases from 0° to −78°C (*31*). A detailed mechanism has been suggested for formation of ionic precursors responsible for initiation (*32*).

Polymerization of styrene. Various other monomers will also polymerize by ionic means when they are irradiated at low temperatures and with additives (*33*). For example, low-temperature polymerization of styrene dissolved in chlorinated solvents with a large dielectric constant is not affected by most

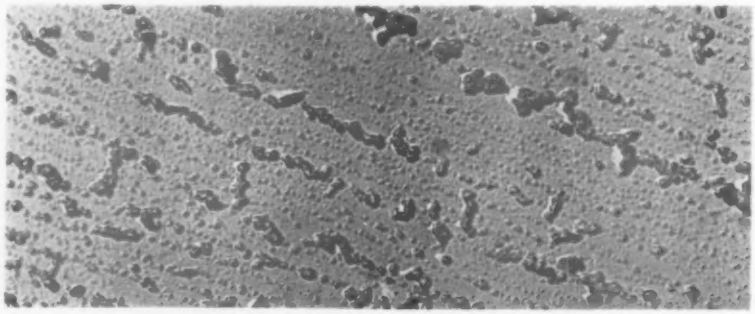

FIG. 2. ELECTRON MICROGRAPH of single acrylamide crystal subjected to small x-ray dose shows that polymerization occurs in localized areas that appear to be parallel to privileged lattice direction

free-radical scavengers (*31, 34, 35*); its rate is directly proportional to the radiation dose rate, and it has a negative activation energy of −2.5 kcal/mole. On the other hand, just as they do in conventional cationic polymerizations, alcohols, esters and carbonyl groups strongly retard the reaction. Studies of copolymerization of styrene with methyl methacrylate at −78°C in chlorinated solvents further confirm the cationic character of the process. This reaction may in fact be initiated by the hydrogen chloride arising from radiolysis of the solvent (*36*).

By contrast, copolymerization of styrene with methyl methacrylate in toluene solution at −78°C proceeds by an anionic mechanism when alumina is added to the reaction mixture (*37*).

Additional polymerizations. Further ionic polymerizations occur when butadiene (*38, 39*), isoprene (*40–42*), pinene (*19, 44*), ethenesulfonamide (*43*) and methyl methacrylate, styrene and acrylonitrile dissolved in amines and in dimethylformamide are irradiated (*44, 45*). In the last two systems the reaction probably occurs by an anionic mechanism. In addition various olefins dimerize under irradiation by ionic processes (*46, 47*).

Solid-State Polymerizations

Although the mechanism by which monomers polymerize when irradiated in the solid state is still under debate, both ionic and free-radical processes may be involved (*48*).

The most detailed studies of solid-monomer polymerizations have been conducted with acrylamide (*49–52*). When you irradiate this monomer at room temperature, the polymerization has the typical auto-acceleration of most reactions in which the growing chains have a prolonged life—in fact the reaction actually proceeds for several months after irradiation. The activation energy of the after-effect is 25 kcal/mole (*52*).

Kinetics of the after-effect were examined in pure monomer and also in mixed crystals of acrylamide with propionamide and acetamide. The former compound, which is isomorphous with the monomer, led to a very pronounced drop in the polymer molecular weight probably because of chain transfer. When the change in crystal structure during the reaction was measured by x-ray diffraction (*53*) and examined in polarized light (*54*), the results showed that polymerization proceeds in certain localized regions while the monomer structure remains unaltered in other parts of the crystal. The electron micrograph in Fig. 2, taken after subjecting a single crystal of acrylamide to a small dose of x-rays (*55*), clearly shows that the polymer forms in extremely localized areas that appear to be parallel to a privileged lattice direction. The reaction probably occurs by a free-radical mechanism; indeed the yield of polymer molecules closely corresponds to that of the trapped radicals in the irradiated monomer (*52*).

Polymerization studies of other solid monomers include vinyl stearate (*49, 56*), acrylonitrile (*57–59*), styrene (*59, 60*), hexamethylcyclotrisiloxane (*62, 63*), methacrylonitrile (*61*), 3,3-bischloromethyl oxacyclobutane (*64*) and methyl methacrylate dissolved in paraffin oil (*59*). Vinyl stearate polymerizes faster in the liquid state than in the solid, whereas all other monomers exhibit much larger reaction rates in the solid state than immediately above melting point. Figure 3 shows Arrhenius plots for styrene, acrylonitrile and 3,3-bischloromethyl oxacyclobutane. Over-all activation energies are usually positive for the solid monomers (Table 2).

Using azobisisobutyronitrile as a sensitizer, methacrylic acid has been photopolymerized in the solid state (*66*). This reaction presumably involves only free radicals. On the other hand, polymerization of solid hexamethylcyclotrisiloxane almost certainly occurs by an ionic mechanism since this monomer is only known to polymerize when treated with ionic catalysts. Irradiation of the liquid monomer (above 64°C) does not lead to any appreciable amount of polymer, but in the solid state a large molecular-weight polymer results (*62, 63*). Below the melting point of the monomer, the reaction has an activation energy of 9.6 kcal/mole. The over-all rate is approximately first order with respect to radiation dose rate. At high degrees of conversion the polymer is crosslinked. A similar kinetic behavior occurs in 3,3-bischloromethyl oxacyclobutane (*64*).

Other nonvinyl monomers that have been successfully polymerized in the crystalline state include the following: formaldehyde (*65*), acetaldehyde (*67*), trioxane (*68*), diketene (*69*) and β-propiolactone (*70*). In all cases, the reaction rate is drastically reduced when the monomer is irradiated in the liquid state. This property seems to be characteristic of numerous solid-state polymerizations. We expect ionic processes to occur much more efficiently in irradiated solids than in liquids because the ion pairs recombine very

TABLE 2—Activation Energies in Solid-Monomer Polymerizations

Monomer	*Temperatures (°C)*	*Activation energies (kcal/mole)*	*Reference*
Acrylamide	0 to +65	3.0 to 4.7	*49, 50*
Vinyl stearate	−30 to +25	1.5	*49, 56*
Acrylonitrile	−196 to −83	0.4 to 1.0	*57–59*
Methacrylonitrile	−196 to −30	0.3	*61*
Styrene	−78 to −30	11.6	*59*
Methyl methacrylate in paraffin oil (50/50)	−130 to −78	3.0	*59*
Hexamethylcyclotrisiloxane	+15 to +62	9.6	*62*
Formaldehyde	−160 to −120	(slightly negative)	*65*
3,3-bischloromethyl oxacyclobutane	−78 to +15	6.0	*64*

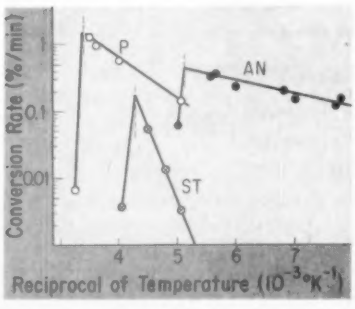

FIG. 3. SOLID-STATE polymerizations at various temperatures for styrene (ST), acrylonitrile (AN) and 3,3-bischloromethyl oxacyclobutane (P)

rapidly in liquids whereas in solids electrons may become trapped and long-lived charged species may consequently form. This view would account for the sudden rise observed in reaction rate upon crystallization.

Because crystal structure appears to affect the reaction rate of monomers, its influence has been investigated. Experimental results show that acrylamide polymerizes faster when one irradiates microcrystalline structures than when one irradiates large monocrystals (*50*). In contrast, acrylonitrile, β-propiolactone, 3,3-bis-chloromethyl oxacyclobutane and methacrylic acid polymerize faster in large crystals than in microcrystals.

An interesting effect takes place with acrylonitrile. When the monomer is irradiated continuously at −196°C, a limit in polymerization occurs at ~4.5% of conversion (*58, 59*). Interestingly, however, if the irradiated monomer is melted, recrystallized and then subjected to further irradiation, the reaction proceeds to much higher conversions (*58, 59*). During experiments with the monomer it was discovered that the irradiated reaction vessels became electrically charged and that if the irradiated samples were grounded, polymerization proceeded beyond the limiting conversion (*71*). Finally, after irradiating the solid monomer in a grounded stainless-steel vessel, one got a linear conversion curve at least up to 25% conversion (*59*). These results show that some ionized species are the precursors of the active centers that initiate the polymerization. Under ordinary irradiation conditions a saturation is reached that may result from the combination of these species.

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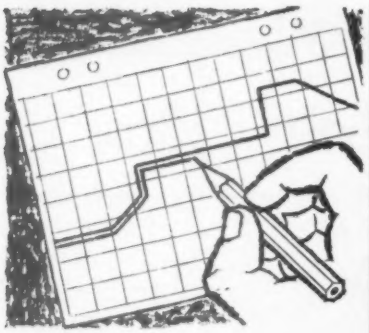

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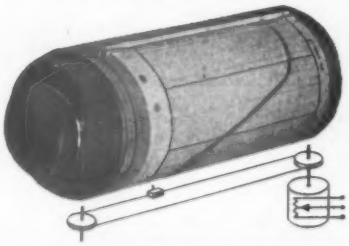

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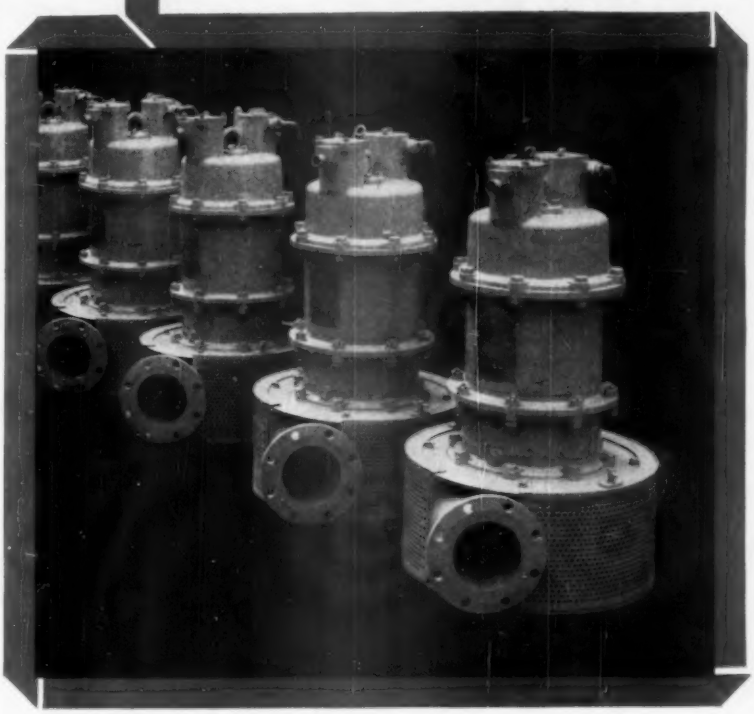

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Cheap, Fast Automatic Activation Analysis

In Texas agricultural chemists are faced with hundreds of thousands of routine analyses, and they fall behind. To get them out of their difficulty, says Richard E. Wainerdi of Texas A & M, give them the facilities for automatic neutron-activation analysis. According to Wainerdi a good system of this kind would perform routine analyses more cheaply than any other system one could devise.

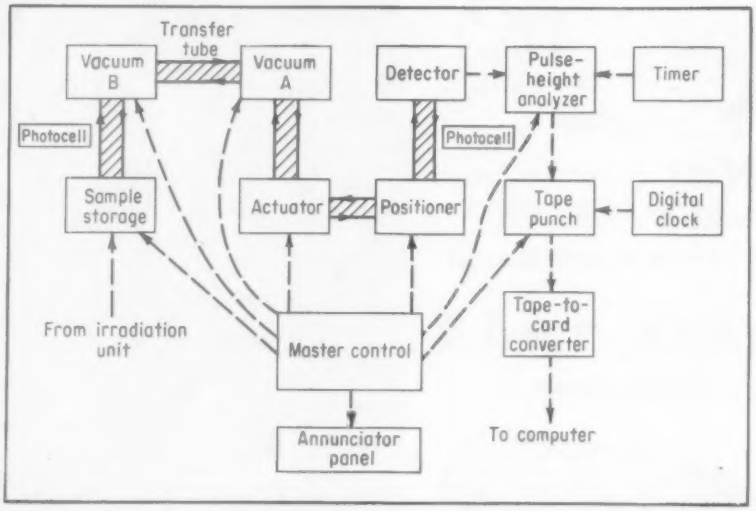
He points out that analytical techniques are such that in all of history probably no more than 5,000 sea-water samples have been completely analyzed. Yet one large Houston medical center is faced with 3,000 blood samples per day. In any situation that presents an analyst with more than 50–100 samples at a time; investment of ~$50,000 would make possible completely routine analysis. At present 72 elements of the 92 yield their secrets to slow neutrons; the number increases to 85 when one can use fast neutrons as well.

At the Activation Analysis Research Laboratory of Texas A & M, Wainerdi and his colleagues have been gradually working toward a completely automatic system. They prepare samples in standard vials, expose them to a Texas Nuclear Co. neutron source (*1*) or a reactor and then count with an automatic system that produces data on punched cards.

Data Handling

Cost for a system need not include a computer. Instead the analyst can gather his data on one set of cards, his program on another set and ship the whole collection to the nearest appropriate computer. One group who are experimenting with the method in the Phillipines are sending their cards to Tokyo for data analysis.

The Texas A & M group has written two computer programs for use with its automatic system (*2, 3*). The first uses a sophisticated spectrum-stripping technique. Since half-life is one identity test, each sample must be counted at least twice. The second program uses, instead of spectrum stripping, a comparison between the unknown spectrum and the spectra from pure specimens in a simultaneous matrix solution. Necessary conditions are that the unknown spectrum not be too complex nor too unbalanced.



AUTOMATIC COUNTING SYSTEM takes dialed sample from 10 × 10 array, counts it for preset time, returns sample to storage and produces data on punched cards

Automatic Analysis

Our figure shows the system with which Wainerdi and his colleagues count and record their spectra after samples have been prepared in standard vials and exposed to neutrons. To set it in operation one dials a sample number at the master control unit. In response a vacuum pickup moves to the dialed sample in a 10 × 10 sample storage. Vacuum B and then Vacuum A (both produced by commercial vacuum cleaners) are automatically actuated so that the sample goes to the actuator and positioner for placement before the scintillation crystal detector.

After it has been counted for a preset time, the sample returns to storage while data proceeds from a 256-channel pulse-height analyzer through a tape punch and a tape-to-card converter to a set of output cards. On the way the time of year (in minutes and hundredths of minutes) is added to the data from a digital clock especially designed for the purpose.

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3. L. E. Fite, D. Gibbons, R. E. Wainerdi, "Computer Coupled Automatic Activation Analysis," TEES 2671-1 (1961)

Activation Analysis: A Course and a Conference

Trends and techniques in activation analysis will be the subject of a course (December 4–14) and a conference (December 15, 16) at Texas A & M under joint sponsorship of the International Atomic Energy Agency, The Office of Isotopes Development, U. S. AEC and the college (see "Nuclear Calendar," p. 92 and NU, Sept. '61, 31). Instructors for the course and chairmen for the conference will be George Leddicotte, Oak Ridge National Laboratory; Derek Gibbons, UKAEA, Harwell, England; Vincent P. Guinn, Shell Development Co., Emeryville, Calif. and Richard E. Wainerdi, Texas A & M.

Subjects will include radiochemical separations, gamma-ray spectrometry, data processing and applications of activation analysis.

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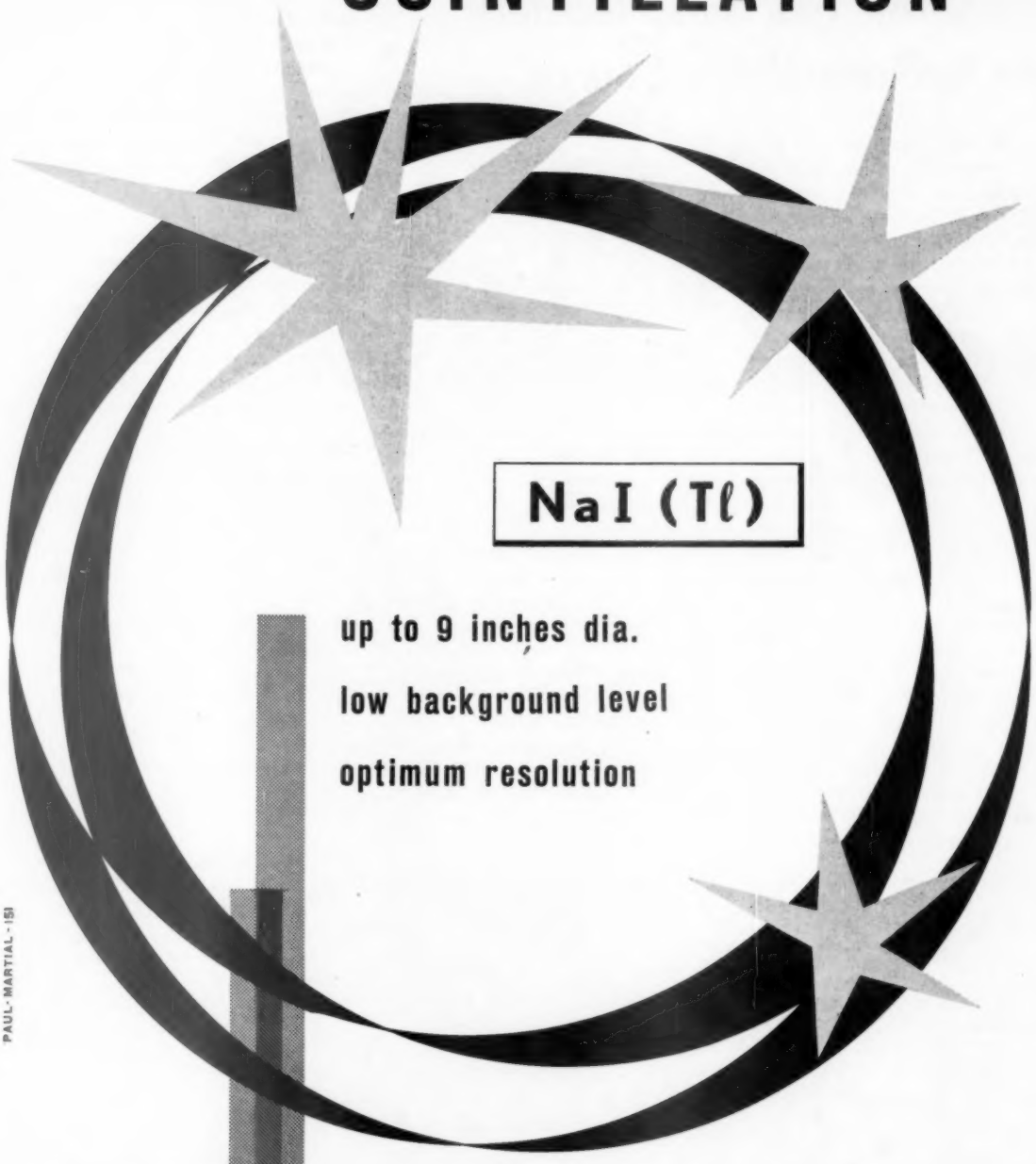

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63,000-Mw Fast Burst Reactor—New Radiation-Pulse Source

A potent new "portable" source of intense fast-neutron pulses soon will be operating atop a 1,500-ft tower at AEC's Nevada Test Site (in comparison, the 102-story Empire State Building is 1,472 ft high, including the 222-ft TV antenna perched on top). Designed and built by United Nuclear Corp. (except for the core and movable-fuel control rods, which were fabricated at Oak Ridge), the unshielded and unmoderated Fast Burst Reactor will closely simulate a primary fission spectrum. FBR is a direct descendant of the two Godiva fast reactors at Los Alamos. The table compares their performances, as well as showing the pulse outputs of Argonne's Treat and General Atomic's Triga reactors (which operate on thermal neutrons).

Performances of Pulse Reactors

Reactor	*Pulse width (μsec)*	*Peak power (Mw)*	*Integrated fissions*	*Cooling time (hr)*
Godiva-1	35	~10,000	1.5×10^{16}	1/2
Godiva-2	~35	~13,000	2.7×10^{16}	1/2
FBR	~40	63,000	10^{17}	<1
Treat	≥100,000	5,000	3×10^{13}	~5
Triga-1, -2	40,000	250	3×10^{17}	0.1
Triga-F	13,000	1,200	5.4×10^{17}	0.1

To pulse FBR the operator at the console in a shielded bunker near the tower base brings FBR critical by partly inserting the 1-in.-diameter "mass-adjust" rod and the 3½-in. "safety block." Then he pulls out the safety block (without which FBR can not go critical regardless of where other control rods are located), positions the mass-adjust rod to preset the pulse size, inserts the safety block and drives the ¾-in. "burst" rod into the core cavity. The resulting rapid reactivity rise makes the core prompt critical and power rises with an initial 13-μsec period. When the core heats enough that the negative temperature coefficient due to thermal expansion causes reactivity to drop, power falls (within 35 μsec after the pulse starts) and the reactor remains critical with the aid of delayed neutrons. About 30–40 msec after the burst the scram circuit drives the safety block from the core and FBR becomes subcritical and shuts down. After less than an hour has elapsed the core cools enough to be ready for another burst.

Steady power (1 kw with natural-convection cooling, 10 kw with a simple air-blower cooling system) can be had if the operator moves a ⅝-in.-diameter regulating rod instead of the burst rod; during pulse operation this regulating rod remains stationary in the core.

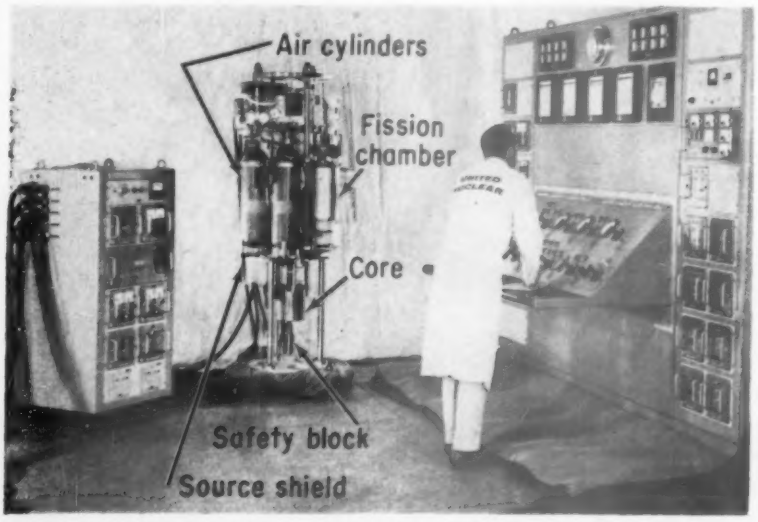
Whether FBR pulses or operates at steady power the small buildup of long-lived fission products permits direct maintenance after a cooling period.

Godiva-plus performance of FBR derives from two novel features: a 2-in.-diameter stainless-steel rod down the middle of the safety block reduces the temperature peak at the core center, and 10 w/o molybdenum alloyed with the uranium in the core and control rods permits the core to heat up repetitively to 740°F above ambient.

The Nevada test program, named Operation BREN (Bare Reactor Experiment in Nevada), will provide data to relate measured radiation doses to the biological effects of radiation observed in the populations of Hiroshima and Nagasaki. Such experiments, which will help define how to design buildings and shelters that shield people from bomb radiations, have been impossible since the U. S. ceased bomb tests three years ago. Even so, a bomb test might not give the data desired.

When Oak Ridge completes fueling and startup tests this month, FBR will be shipped to Nevada for installation on the tower elevator. BREN tests will begin in November or December. But these shielding tests are incidental to the main objectives of the Fast Burst Reactor program; after February FBR will return to Oak Ridge.

Oak Ridge National Laboratory will install FBR in a new $1.5-million biomedical-research facility located between hills east of the Tower Shielding Facility and two miles from the main X-10 area. In this, its ground-level permanent home, FBR will serve as radiation source for radiation dosimetry and radiobiological research. ORNL also will use it for studies of solid-state physics, radiation chemistry and neutron physics.



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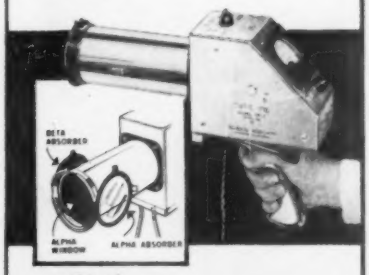

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NUCLEAR BOOKSHELF

Nuclear Engineering

by GILBERT CAHEN and PIERRE TREILLE (translated by GILBERT B. MELESE) (Allyn and Bacon, Inc., Englewood Cliffs, N. J., 1961, $8.50, 395 pages)

Elements of Nuclear Engineering

by GLENN MURPHY (John Wiley and Sons, Inc., New York, 1961, $7.50, 213 pages)

Reviewed by ROBERT WAYNE HOUSTON, Director, Industrial Reactor Laboratories, Inc., Plainsboro, New Jersey

To an already impressively large list of texts that survey the field of nuclear engineering, now come two additional volumes and one may well wonder what has justified their publication. The objective is an elusive one, yet clearly aimed at improved pedagogy of a complex but fascinating subject that is just as clearly still wet behind the ears and trying, perhaps, to compete with the traditional disciplines of engineering education. It seems to me, however, that the existence of survey courses in a subject, and the texts that serve them, are evidence of uncertainty regarding the status of the subject, and if one wishes to promote it to full-fledged disciplinary rank, it is not best accomplished by the proliferation of introductory surveys.

These two texts are not, then, offered as scholarly works but rather as separate subjective views as to how potentially serious nuclear-engineering students should be introduced to a not yet sharply focused field of engineering specialization. In my opinion the able translation of an already successful French text represents the better introduction of the two here considered. It is aimed at seniors and first year graduate students and contains enough up-to-date factual information to serve as a student reference text. It has a more scientific tone than Dr. Murphy's book and, although it is clearly of European origin, it gives a more balanced picture of the nuclear field the world over. For a very slightly higher price, in twice as many pages there are twice as many excellent line drawings and three times as many useful tables of information, particularly in the excellent chapters on materials and on radiation effects. Both texts have over a hundred problems but few could be classified as comprehensive and there are very few illustrative examples of solved problems that many students find very helpful.

Rather few typographical errors were found in the Melese translation although the occasional appearance of commas for decimal points in the continental tradition may require some explanations to American students. Relatively minor bones of contention include an unorthodox definition of α in the reactor-theory section, an apparent misuse of the removal-cross-section concept in multigroup theory, and the persistent use of the somewhat high figure of 23,000 kwh/gm of U^{235} for the energy production in a typical fission reactor.

Dr. Murphy's text, intended for undergraduates, conveys the impression that one is reading a series of lectures since little more is covered in the text than can conveniently be put into a semester's lecture course. While the style is clear and very readable, like a mystery, once read it is likely to be laid aside and not picked up again since it can hardly serve as a reference. Nor was it intended as such.

Somewhat more errors catch the reader's eye in this text, some clearly typographical as in the two prominent figures in Chapter 1 referring to the "fusion" of uranium and a misconstructed exponent in the empirical equation for nuclear radii in Chapter 2. A later reference to electromagnetic protons is quite excusable; however, an apparent misunderstanding of the distinction between neutron flux—a grand misnomer—and neutron current density on page 107 could leave impressionable and generally noncritical students in a quandary.

The treatment of radiation-protection jargon in the two texts affords an interesting comparison since both devote about the same amount of space to it. I think the Melese translation clearly comes out on top as more easily understood and more accurate, although this impression is influenced in part by Dr. Murphy's statement that "in assaying biological damage or potential damage, it is only the total amount of radiation energy absorbed that is significant." As far as I am aware, such a statement applies only to genetic effects, and if the misconception expressed were widely disseminated among potential nuclear engineers, it could have a serious adverse effect on the future development of the whole nuclear field. (*Continued*)

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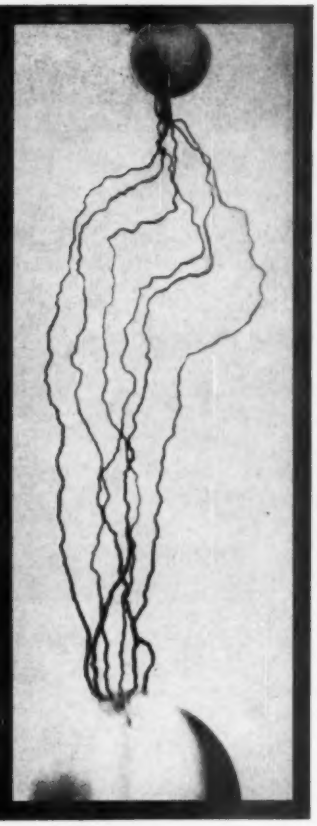

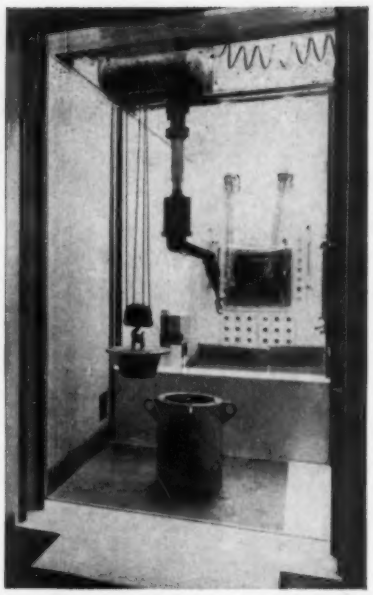

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HOT CELLS

- No sign of degradation after three years of radiation exposure
- Easy to wash down with ordinary detergent

Research conducted in the hot cells at Vallecitos Atomic Laboratory is benefiting many industries. At this General Electric facility near San Francisco, studies include experiments on the effects of radiation on metals, fuels and other materials, with a view to improving properties and performance.

Four years ago, the cells were coated inside and out with a three coat application of Phenoline 305, a slick-surface, modified phenolic-base material highly resistant to impact and degradation from radiation. For the past three years, interior surfaces have been routinely exposed to more than 1,000 Roentgens of radiation per hour.

To date, no deterioration in the protective coating is evident. No repainting has been needed.

Surfaces are washed down by remote control with an ordinary floor polisher and household detergent.

■ Write for detailed information on Carboline's Phenoline 305, the protective coating for concrete and steel, recommended for areas where maximum protection is demanded.

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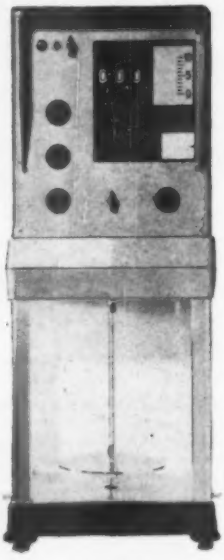
Mettler Balance News

High Capacity and Remote Control . . .

Highly precise weighings of radioactive, poisonous or explosive materials can be made safely and easily on a new series of Mettler analytical balances which can be operated by remote control.

Added to the Mettler Line of more than 50 basic balance models are the W5/11 (capacity 5000g) and the W8/11 (Capacity 8000g). The well-known Mettler B5 is now also available with remote controls (model B5/11).

Both high capacity balances (W5 and W8) have an optical scale range of 10g, sensitivity of 1 mg per vernier division and precision of ± 1mg. Readability is direct to 1mg and by estimation to 0.5mg. The weight sets are adjusted to well within U.S. Class S tolerances. Both the W5 and W8 are available without remote controls for manual operation. These balances, as well as the B5/11 can be operated manually even if equipped with remote controls.



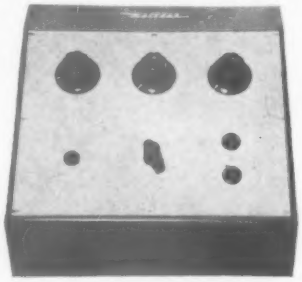
TYPE W5

Errors Designed Out, Speed Designed In . . .

As is the case with all Mettler Balances, the W5 and W8 models operate on the substitution principle, comparing sample and calibrated weights on the same beam arm. Thus only two knife edges are required, a lever-arm error cannot occur, and sensitivity is constant throughout the weighing range of the balance.

A unique mechanical system makes an automatic preliminary weighing to the nearest 10g. This eliminates the need to make step by step trial weighings in the partial release position. Once the rough weight has been determined, calibrated weights are quickly dialed and are lifted off of the suspension system simultaneously, thus reducing abrasive wear on the weights to an absolute minimum.

A complete weighing (including zero point adjustment) can be made within three minutes. Zero point setting, preliminary weighing, weight selection, beam release and arrest, are all operated by remote control. Samples are placed on the pan by mechanical manipulators or through glove boxes; in some cases special conveyors are used.



REMOTE CONTROL PANEL

Safety and Convenience for the Operator . . .

Remotely operated balances insure safety when working with high levels of radioactivity such as are found in fuel cores or contaminated specimens. They also permit greater efficiency when concerned with threshold levels of radiation.

These fast and reliable remote control units can be used to determine the density of radioactive substances, and to measure density changes in radioactive fuel sources (in this way the life of a fuel supply can be determined.)

Explosive materials can be compounded behind thick protective shields. Should the protective barrier not permit use of glass windows, remote operation can be monitored and readings made by closed circuit television.

Poisonous chemical compounds and bacteriological substances can be effectively weighed in isolation chambers. Balances can be sterilized and introduced in gnotobiotic systems.

The large optical scale of W5/11 and W8/11 balances makes it possible to read results from a distance of 14 feet without use of optical aids. On the B5/11 the optical scale and vernier can be read easily at distances of more than 15 feet with the aid of a telescope provided as an accessory.

Mettler has by far the greatest experience in the design and construction of two knife edge, single pan substitution balances. Mettler also leads the field in development of remote operating balances.

For complete information write

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Nuclear Bookshelf

Department starts on page 74

BOOKS RECEIVED

Selected Topics in Radiation Dosimetry (IAEA, Vienna, Austria, 1961, 688 pages, $9.50). The 70 papers presented at the IAEA symposium in Vienna June 7–11, 1960, are contained in this volume under the following headings: Problems Related to Exposure and Absorbed Dose, Ionization Chambers, Scintillation Devices, Photographic Dosimetry, Chemical Methods, Threshold-Neutron Detectors, Counting Devices and Ionization Chambers for Neutron-Dose Determination, Solid-State Dosimeters, Dosimetry for Accelerators or Reactors and Dosimetry on Critical Assemblies.

Progress in Nuclear Energy, Series II, Vol. 2, edited by H. R. McK. Hyder (Pergamon Press, New York, 1961, 552 pages, $15). In this second volume in a series of twelve subjects covering papers from the 1958 Geneva Conference, 16 papers review work with zero-energy fast reactors, SPERT-I safety studies and fast-neutron power-reactor studies with ZPR-III.

Fuel Reprocessing, Vol. II of Reactor Handbook, 2nd ed., edited by S. M. Stoller and R. B. Richards (Interscience Publishers, New York, 1961, 665 pages, $21.40). Much of the material declassified since the first edition came out has been added to this edition. In addition the editors have extended the coverage of the first edition to include material on reconversion, isotope separation and plant and equipment design and cost. The content also covers aqueous and non-aqueous separation processes, waste disposal and engineering problems.

World Nuclear Directory 1961, edited by A. W. Haslett (Vallancey Press, London, England, 1961, 510 pages, $21). In this companion volume to "Who's Who in Atoms" are listed over 2,000 organizations from more than 70 countries. Listings include the full organization title and address as well as the names of senior personnel of agencies, authorities, boards, commissions, societies, government departments, divisions of the armed services, insurance and power groups, universities and industries involved in nuclear research and development.

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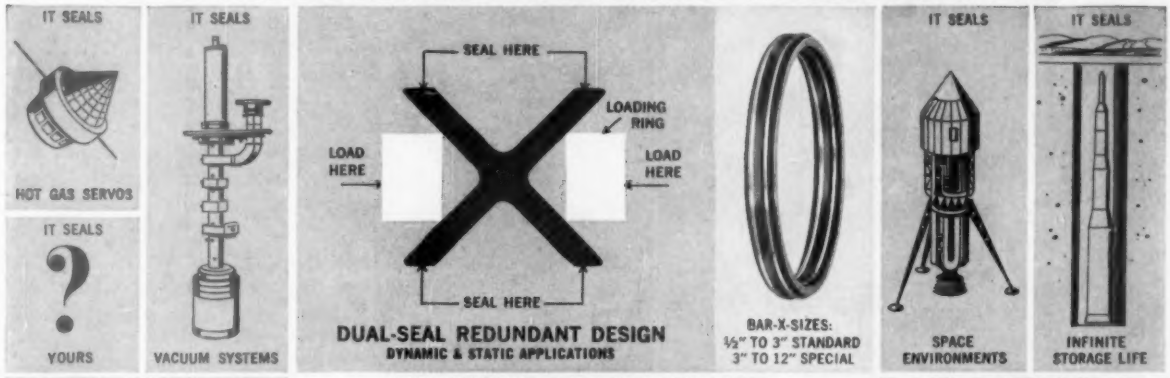

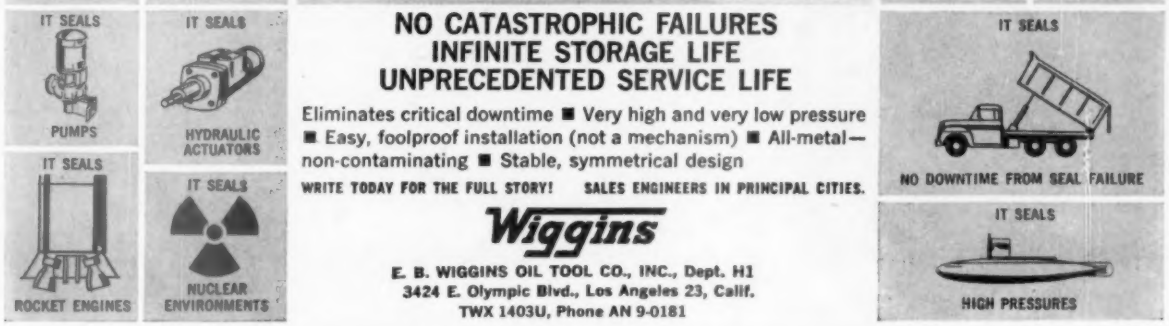
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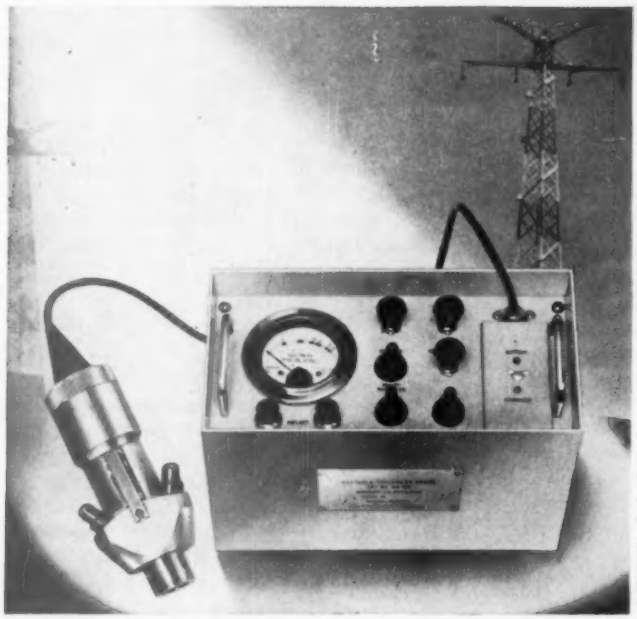

The purpose of the Burndept BN.119 is to provide a portable gauge capable of testing the condition of zinc-on-steel (galvanised) plating. The use of BETA backscatter technique enables this instrument to assess accurately the thickness of the plating. A BETA source is mounted in the same casing as an electronic detector and probe. Radiation from the source penetrates the zinc plating but is reflected back from the steel on to the detector. The amount of reflected radiation reaching the detector is precisely relative to the thickness of the plating, and is registered by means of a transistorised metering instrument. Completely portable, rugged in construction, and suitable for use by unskilled personnel. Time taken for each test reading is approximately one minute. The plating is, of course, completely unharmed. Those responsible for large expanses of galvanised surfaces (tanks, pylons etc.) will find BN.119 by far the most efficient and economical method of ensuring the regular testing of plating condition.

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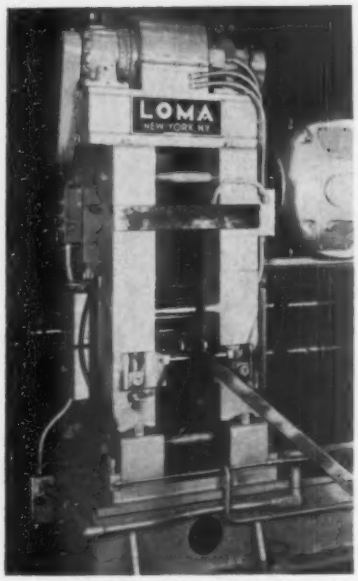

A wide variety of metallurgical processing work can now be performed by a single mill facility due to the development of this compact and versatile LOMA 2-high/4-high Combination Rolling Mill. The equipment is suitable for both hot and cold work, and allows both shapes and flat stock to be rolled, with or without the application of tension.

The machine is equipped with extra large capacity mill housings, roll journals, universal spindles and drive transmission. This heavy-duty design allows the mill to take reductions of more than 50 per cent per pass while maintaining tolerances as close as 5 per cent of thickness.

Change-over from the 8½ in. x 10 in. 2-high to the 2½ in. & 8½ in. x 10 in. 4-high setup requires only 30 minutes. The 2-high arrangement is used for either hot or cold breakdown rolling of plate and sheet, and grooved rolls are also available to process rounds, squares and other shapes. In the 4-high setup strip is cold finish rolled to gauges as thin as 0.002 in.

The LOMA mill is furnished with high-strength steel housings, twin-handwheel or dual-motor wormdrive screwdowns, universal joint spindles, herringbone gearing, and an extra heavy-duty 25 h.p. variable-speed drive. The rolls are made of forged alloy steel and are hardened to 100 Shore Scleroscope. The roll necks are mounted in super-precision needle roller bearings having a total separating force capacity of 350,000 lbs. The bearings are continuously lubricated by a closed oil circulating system.

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MACHINE MFG. CO., INC.
114 East 32nd Street
New York 16, N. Y.

PRODUCTS AND MATERIALS

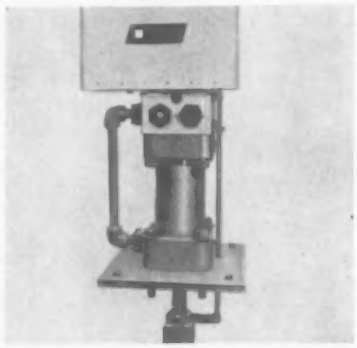
Helium leak detector (above) together with an auxiliary pumping unit connected to enclosure tests individual fuel elements. After being filled with helium at reduced pressure, fuel element is loaded into enclosure which is then evacuated to 10^{-5} mm Hg. Mass-spectrometer leak detector tuned to the helium peak then measures pressure rise over 10 min.—20th Century Electronics Ltd., King Henry's Dr., New Addington, Croydon, Surrey England.

Radiation survey meter. Portable survey meter with transistors designed to double as a laboratory and field survey unit in the 0–50 mr/hr range is powered by 5 1.5-volt flashlight batteries. Model 701, which weighs less than 5 lb, operates continuously for 100 hr.—Lionel Electronic Laboratories, 1226 Flushing Ave., Brooklyn 37, N. Y.

Two 55,000-gal spheres (above) to store liquid hydrogen for Project Rover have been constructed at Jackass Flats, Nev. Outer steel shell of each tank is just over 30 ft in diameter; inner stainless-steel shell is designed for 100 psig pressure.—Graver Tank & Manufacturing Co., 35 E. Wacker Dr., Chicago 1, Ill.

Electron-beam welder, Model Mark VI, gives spot, longitudinal, annular and circumferential welds of refractory and reactive metals such as beryllium, titanium and tantalum. System includes electron gun, vacuum chamber, mechanical roughing and diffusion pumps, power supply and console.—Alloyd Electronics Corp., 37 Cambridge Pkwy, Cambridge 42, Mass.

Tube coupling with seal, Dynatube, gives dynamic sealing for all liquids and gases up to 700°F; it also remains leak-proof under cryogenic conditions. Testing shows that seal can handle 5,000-psi helium.—Resistoflex Corp., Roseland, N. J.



Valve actuator (above), to be installed in the Pathfinder Plant at Sioux Falls, S. D., provides 50,000 lb of force in either direction. The 6-in. stroke, completed in 0.3 sec, operates a 12 in. valve against steam pressures of 550 psig.—CompuDyne Corp., Hatboro, Pa.

Globe valves that are hermetically sealed and resist high temperatures come in ½–2-in. sizes. In handling radioisotopes these valves have zero leakage to atmosphere, and operate at temperatures up to 600°F and pressures up to 2,200 psi.—United Shoe Machinery Corp., 140 Federal St., Boston 7, Mass.

Two small Hughes linacs. One, a mono-pulse linac, no larger than an office desk produces gamma pulses singly or as frequently as 1 pps. Its radiation intensity is 10 r/sec at 6–8 Mev. The other, a steady-state linac, produces 4- to 12-Mev electrons.—Hughes Aircraft Co., Florence Ave & Teale St., Culver City, Calif. (*Continued*)

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Transcint and Air Sampler

• Model 963-T Transcint. Transistorized as above. For measurement of fast or slow neutrons and gamma rays.

• Series 1020 Air Sampler. To facilitate rapid field measurements of airborne radon daughter products. A filter holder accommodates a standard molecular membrane filter. Operates from a 6 volt battery. Used in association with the Transcint 1001 to measure alpha activity on the filter.

• Radioisotope Analyzer. Designed to enable the user to quickly check the identity of a radioisotope and also to measure its activity. It is used with those isotopes which emit gamma rays.

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Products and Materials

Department starts on page 78

Dual-channel liquid scintillation counter (above), Model 701, measures soft-beta emitters at room temperature. Opening in table at front of control unit provides access to motor-driven elevator that lowers sample into detector assembly.—Nuclear-Chicago Corp., 359 E. Howard Ave., Des Plaines, Ill.

Digital-data recording and alarm scanning systems. Series 7000 uses building-block technique to meet specifications of units without costly over-design and long delivery times. Systems can be designed on practically an "off-the-shelf" basis.—Monitor Systems, Inc., Fort Washington Industrial Park, Fort Washington, Pa.

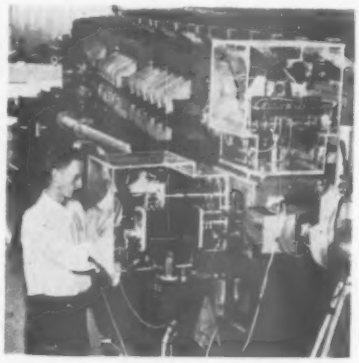
8.8-lb neutron generator gives neutron flux of 10^7 n/cm²/sec by the *d-t* reaction. Source tube uses Penning ion source, one-stage accelerating system, target and replenisher system to produce 14-Mev neutrons.—Norelco Instruments, Philips Electronic Instruments, 750 S. Fulton Ave., Mount Vernon, N. Y.

Guard-ring detectors. Two new semiconductor detectors—NPSG-25 (25–75 volts) and NPSG-75 for particle spectroscopy (75–200 volts)—have guard rings that not only give little noise and thus large energy resolution, but also eliminate current leakage.—Solid State Radiations, Inc., 2261 S. Carmelina, Los Angeles 64, Calif.

High-vacuum valves. Made from stainless steel, these right-angle, O-ring sealed valves come in 4- to 12-in. I.D. sizes.—F. J. Cooke, Inc., 145 Water St., South Norwald, Conn.

Shut-off damper for nuclear uses shuts off air in <1 sec. Unit comes in seven sizes from 15 to 40 in. in diameter, has air capacity up to 25,000 cfm and temperature range up to 175°F.—American SF Products, Inc., Englewood Cliffs, N. J.

Detector-photomultiplier tubes. In new series of NRM light-tight assemblies, scintillator is mounted directly on photomultiplier tube. Magnetic shield protected by aluminum housing encloses tube. Assemblies come with NaI(Tl), stilbene, anthracene, enriched Li^6F-ZnS(Ag) and ZnS(Ag) detectors.—National Radiac Inc., 475 Washington St., Newark 2, N. J.



Television monitors proton beam at AGS, Brookhaven. General Precision television camera (above) and monitor are used by AGS scientists to observe light produced by protons impinging on quartz flag interposed into proton-beam path in accelerator.—General Precision, Inc., 63 Bedford Rd., Pleasantville, N. Y.

Steel to Livermore for cyclotron. U. S. Steel has shipped 14 blocks of precision-machined solid steel weighing from 12 to 21 tons each to Lawrence Radiation Laboratory to make up the magnet core of the new 88-in. cyclotron to be completed early in 1962.—U. S. Steel Corp., 525 William Penn Place, Pittsburgh 30, Pa.

Decade scaler. Designed for small activity counting, Model 100 features five decades, printed circuit, 2,500 volt supply with time delay and built-in elapsed timer.—ATOMasters-Buntaine Corp., 111 W. Jewel Ave., St. Louis 22, Mo.

Dry-film lubricant for space. Hi-T-Lube has performed effectively as a lubricant for 3 hr in thrust bearing tests at temperatures from room temperature to 1,000°F using an applied load of 1,400 lb rotating at 720 rpm and reversing direction every 3 sec. These

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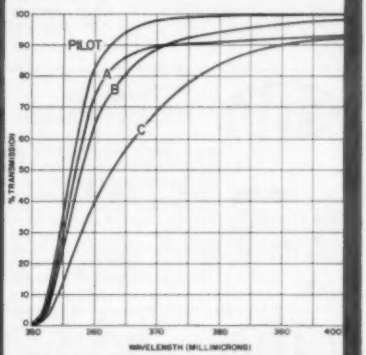

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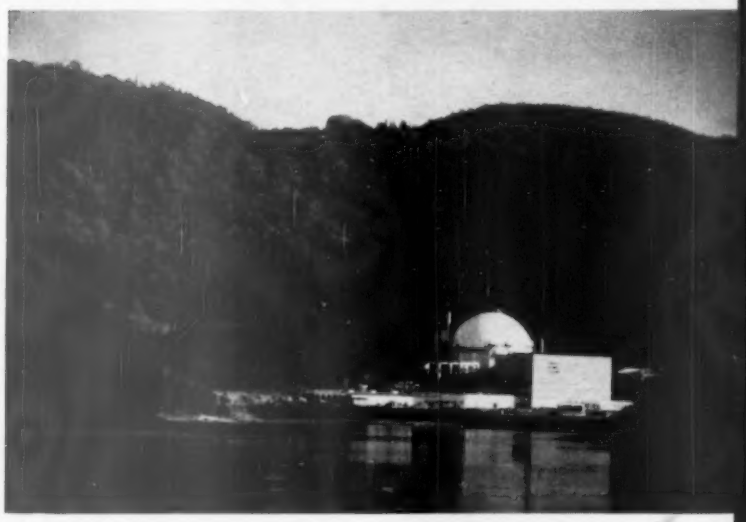

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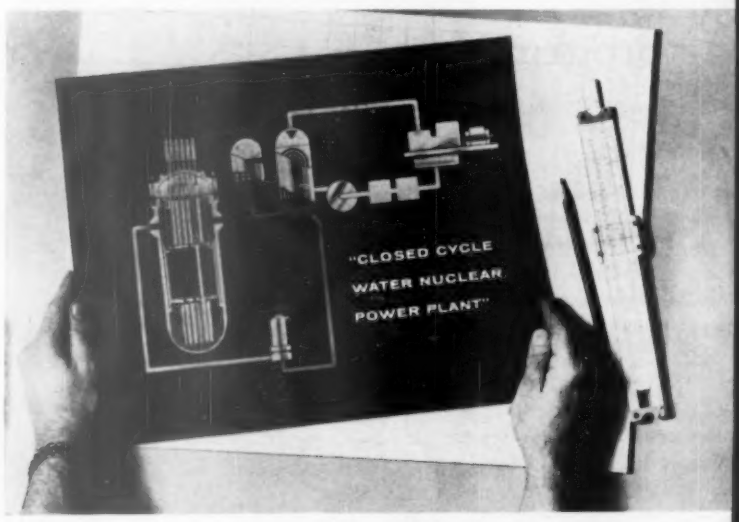

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Products and Materials

Department starts on page 78

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LITERATURE AVAILABLE

Shaftrol Rotary Actuator, SM-11. Jordan Controls, Inc., 3235 W. Hampton Ave., Milwaukee 9, Wis.

Flow Counters. 1 p.; Tracerlab, Inc., 1610 Trapelo Rd., Waltham 59, Mass.

Ultra-Pure Elements with Typical Analyses. 10 pp.; Organic Chemicals. 120 pp.; L. Light and Co., Colnbrook, Bucks, England.

McDonnell Automated Data-Processing and Computing Center. 21 pp.; McDonnell Automation Center, Box 516, St. Louis 66, Mo. (*Continued*)

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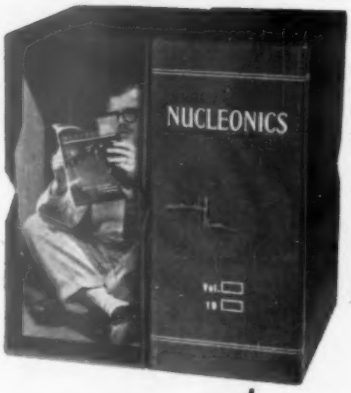

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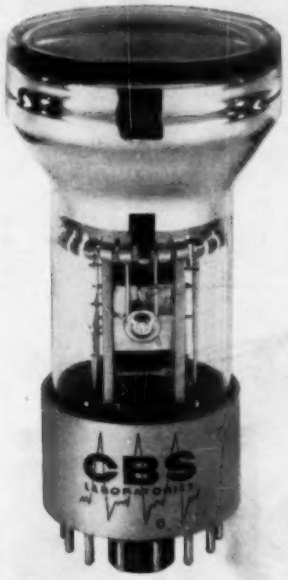

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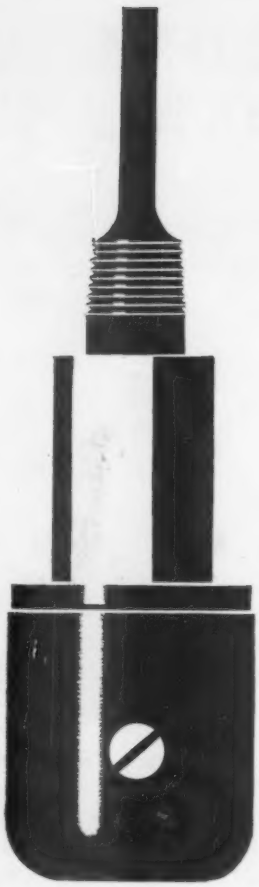

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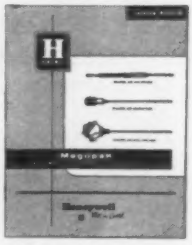

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Activation Foils. 2 pp.; Reactor Experiments, Inc., Box 133–1485 Bayshore Blvd., San Francisco, Calif.

Molecules Marquées. Radioéléments Artificiels. 11 pp.; 156 pp.; Commissariat à L'Energie Atomique, B. P. No. 2, Gif-sur-Yvette (Seine-et-Oise) France.

Metallographic Catalog. (No. E-240) Bausch & Lomb Inc., Rochester 2, N. Y.

Ultra-Pure Labeled Compounds. 4 pp., Hazleton-Nuclear Science Corp., 4062 Fabian Way, Palo Alto, Calif.

Nuclear-Training Instruments. 9 pp.; ATOMasters-Buntaine Corp., St Louis 22, Mo.

Automatic Windowless Integrating 4π Chromatogram Scanner. 4 pp.; **Neutron Demonstrator.** 2 pp.; **Fast-Neutron and γ Dosimetric System.** 2 pp.; Atomic Accessories Inc., 813 W. Merrick Road, Valley Stream, N. Y.

Transistorized Instruments for Radioactivity Measurement and Chromatography. 6 pp.; Packard Instrument Co., Inc., Box 428, La Grange, Ill.

Measuring Instruments for Individual Radiation Protection. 4 pp.; Frieseke und Hoepfner Gmbh, Erlangen-Bruck, West Germany.

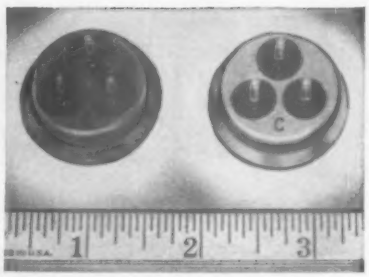
Survey Meters—Dosimeters. 16 pp.; Victoreen Instrument Co., 5806 Hough Ave., Cleveland 3, O.

Crystal Window. (No. 1–61) 4 pp.; The Harshaw Chemical Co., Crystal Division, 1945 E. 97th St., Cleveland 6, O.

Isotope Chambers for Gamma Radiography. 6 pp.; Philips Electronic Instruments, 750 S. Fulton Ave., Mount Vernon, N. Y.

UO_2 for Three Commercial Power Reactors. 8 pp.; Mallinckrodt Nuclear Corporation, St. Louis 7, Mo.

BF_3 Proportional Counters. 1 p.; **Linear Amplifiers.** 4 pp.; Hamner Electronics Co., Inc., Box 531, Princeton, N. J.



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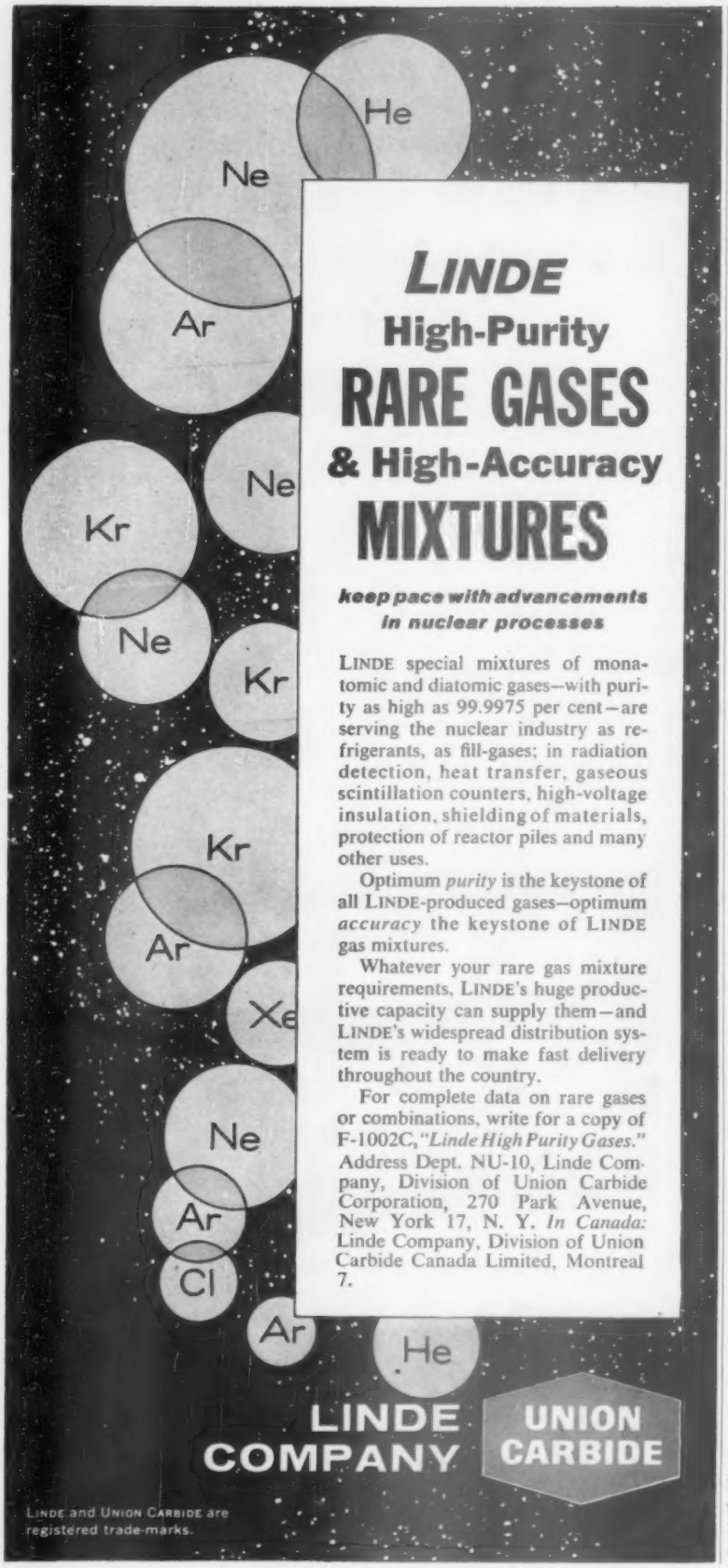
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NEWSMAKERS

Lionel Electronic Laboratories, formerly Anton Electronic Laboratories, has announced several staff appointments: **Luigi M. Ferrari,** formerly with U. S. Hoffman Machine Corp., is the new vice president, manufacturing and administration; **Herbert Kalisman,** with Anton since 1951, has been promoted to general sales manager. **Walter K. Volkers,** recently-appointed president of LEL, announced that it will operate as a completely independent unit of the Lionel Corp., continuing to manufacture Anton nuclear detection instruments and adding new instrument lines.

Robert A. Charpie, assistant director of Oak Ridge National Laboratory since 1955, has been appointed manager of advanced developments for Union Carbide Corp. He will be located in the New York office and will be concerned primarily with projects in solid-state physics, electronics and nucleonics.

Nathan W. Snyder, formerly a government adviser on power and propulsion with the Institute for Defense Analysis, has joined Royal Research Corp., a Royal Industries subsidiary, as director of research and engineering. The appointment reflects Royal's increasing interest in the use of isotopes for auxiliary power and in nuclear rocket and ramjet components.

Carl F. Leyse has been named general manager of Internuclear Company, a subsidiary of Petrolite Corp. Leyse was with Internuclear from 1956 to 1959, then on the research-development staff of General Atomic.

New chief of NASA's Plum Brook Reactor Facility, Sandusky, O., is **Patrick L. Donoughe.** With NASA since 1947 (then the National Advisory Committee for Aeronautics), Donoughe has been involved in nuclear-propulsion studies.

Victor F. Weisskopf has been appointed fourth Director-General of CERN (Organization for Nuclear Energy Research), succeeding J. B. Adams who is returning to England as director of the Culham Controlled Thermonuclear Research Establishment. Weisskopf, who had been Professor of Physics at

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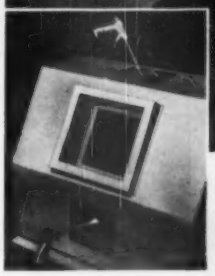

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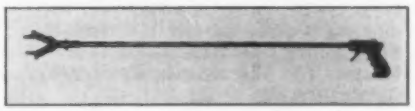

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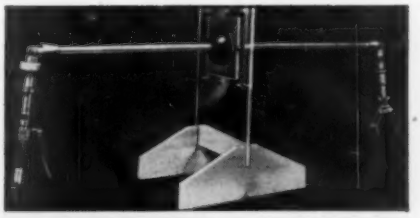

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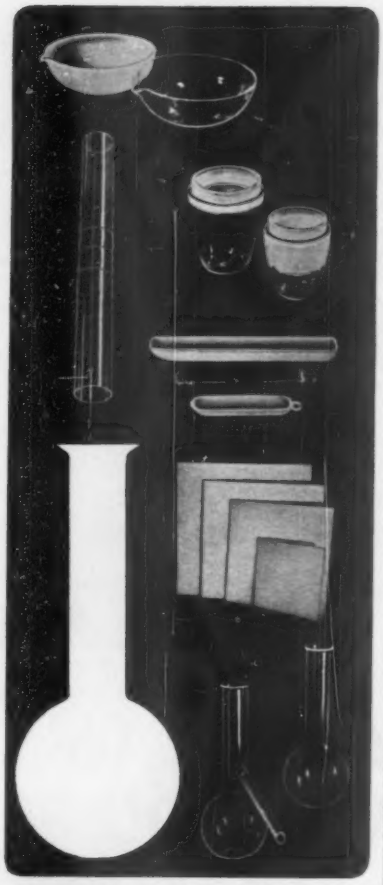

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Newsmakers

Department starts on page 88

MIT, has been with CERN for one year as a member of the directorate for research.

Robert L. Loftness has been named Atomics International's Eastern representative, leaving his previous position as AI's senior management representative at Dynatom, the company's French affiliate. Company officials said that there will no longer be a permanent Paris representative; Hans Polak, with AI's Switzerland office, will look after the company's interest in Dynatom. **Robert H. Sehnert,** Loftness's predecessor in Washington, has been re-assigned to the Canoga Park, Calif. plant. The two transfers are part of a general company reorganization that began in late May.

AEC has appointed **John A. Erlewine** as its senior representative in the U. S. mission to Euratom, succeeding Nelson Sievering who has represented the United States at Euratom since 1959. **Allan M. Labowitz** will serve as AEC scientific represehtative in the U. S. mission, acting as Erlewine's deputy.

W. D. Manly, previously associate director of the ORNL metallurgy div., has been appointed director of the Gas Cooled Reactor Program at Oak Ridge National Laboratory. He will be responsible for contributions to the Experimental Gas Cooled Reactor as well as studies of the Pebble Bed Reactor and experiments on the feasibility of beryllium-cladding.

Andrew Kalitinsky, General Dynamics/Fort Worth nuclear program manager, has been assigned to the position of Apollo program director for General Dynamics/Astronautics in San Diego. The appointment is a result of a contract recently awarded to GD/Astronautics for studies leading to nuclear powerplants for Saturn space vehicles, which will be used to power NASA's Apollo spacecraft.

Boone M. Dawson, previously with Lockheed Nuclear Products Branch in Dawsonville, Ga., has been named director of the Nuclear Geologic Environment Group of Nuclide Analysis Associates, State College, Pa. Bowen will be in charge of design and evaluation of waste disposal systems.

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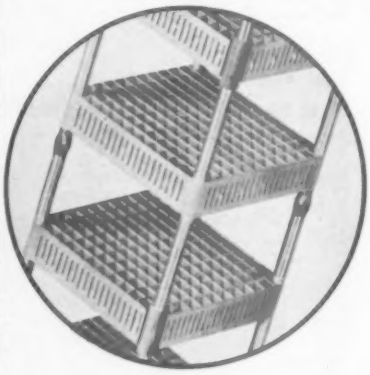

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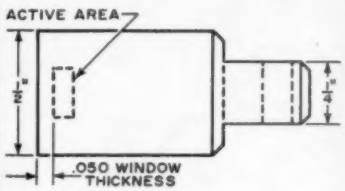

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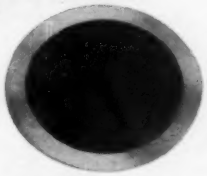

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NUCLEAR CALENDAR

October 9–15—American Rocket Society 1961 Space Flight Report to the Nation, New York (*Coliseum*); papers and exhibits reviewing major technical work in rocketry, missiles and space flight. Contact Roderick L. Hohl, Public Relations Mgr., ARS, 500 Fifth Ave., New York 36, N. Y.

Oct. 10–12—Joint conference on Nuclear Reactor Chemistry and Analytical Chemistry in Nuclear Reactor Technology, Gatlinburg, Tenn., sponsored by Oak Ridge National Lab. Contact ORNL, P. O. Box X, Oak Ridge, Tenn., Attn: W. R. Grimes (Reactor Chemistry) or C. D. Susano (Analytical Chemistry).

Oct. 16–20—IAEA-sponsored Symposium on Programming and Utilization of Research Reactors, Vienna. Contact Public Information, IAEA, Room 2249, United Nations Bldg., New York.

Oct. 19–20—12th Symposium on Corrosion in Nuclear Technology, Paris. Contact Societé de Chimie Industrielle, 28, rue St. Dominique, Paris 7e.

October 20—Fifth annual symposium on Advances in Tracer Methodology sponsored by New England Nuclear Corp., Washington, D. C. (*Shoreham*); review and discussions on use of radioisotopic tracers. Contact Paul A. McNulty, New England Nuclear Corp., 575 Albany St., Boston 18, Mass.

October 23–26—International Symposium on Aero-Space Nuclear Propulsion, jointly sponsored by AEC, NASA, and the IRE PGNS, including review of SNAP, Rover and Pluto programs, Las Vegas, Nev.; contact: D. J. Niehaus, The Bendix Corp., Detroit, Mich.

Nov. 7–10—American Nuclear Society/Atomic Industrial Forum joint meeting, Chicago; includes 9th Hot Laboratories and Equipment Conference and AtomFair '61. ANS contact: J. Kurans, ANS Meeting Chairman, Nuclear-Chicago Corp., 345 E. Howard Ave., Des Plaines, Ill. AIF contact: Conference Manager, AIF, 850 Third Ave., N. Y.

Dec. 15–16—1961 International Conference on Modern Trends in Activation Analysis, A. and M. College of Texas; jointly sponsored by IAEA, AEC div. of Isotopes Development, Activation Analysis Research Lab., Texas A. and M. Contact Richard E. Wainerdi, Activation Analysis Research Lab., Texas A. and M., College Station, Tex.

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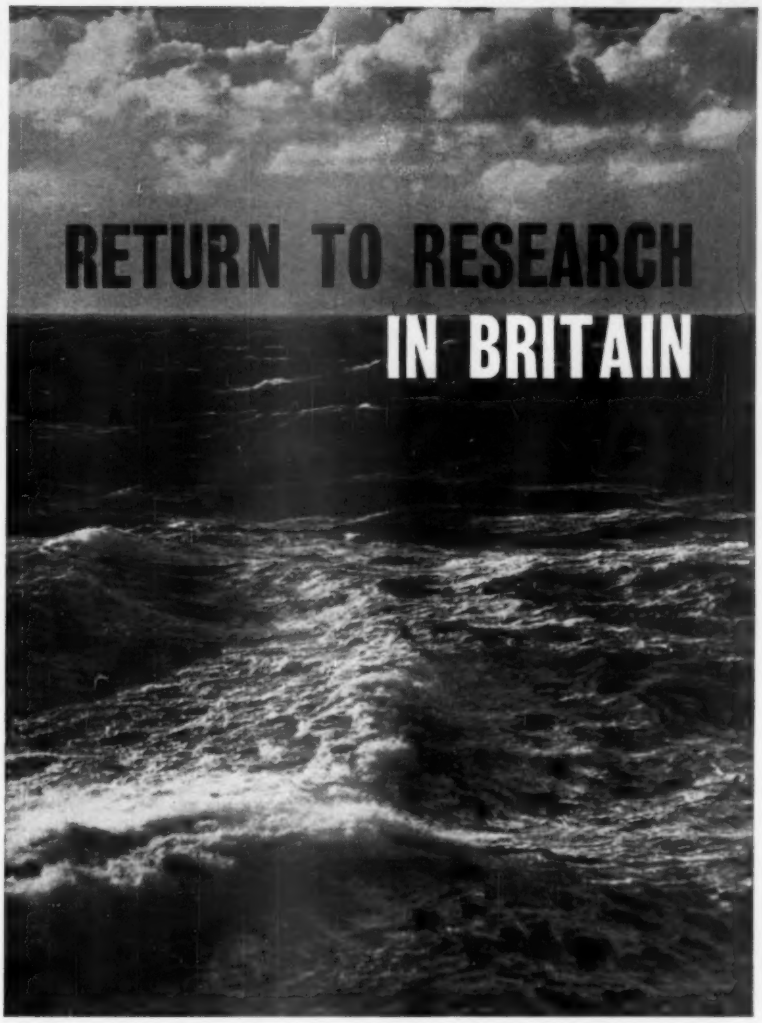

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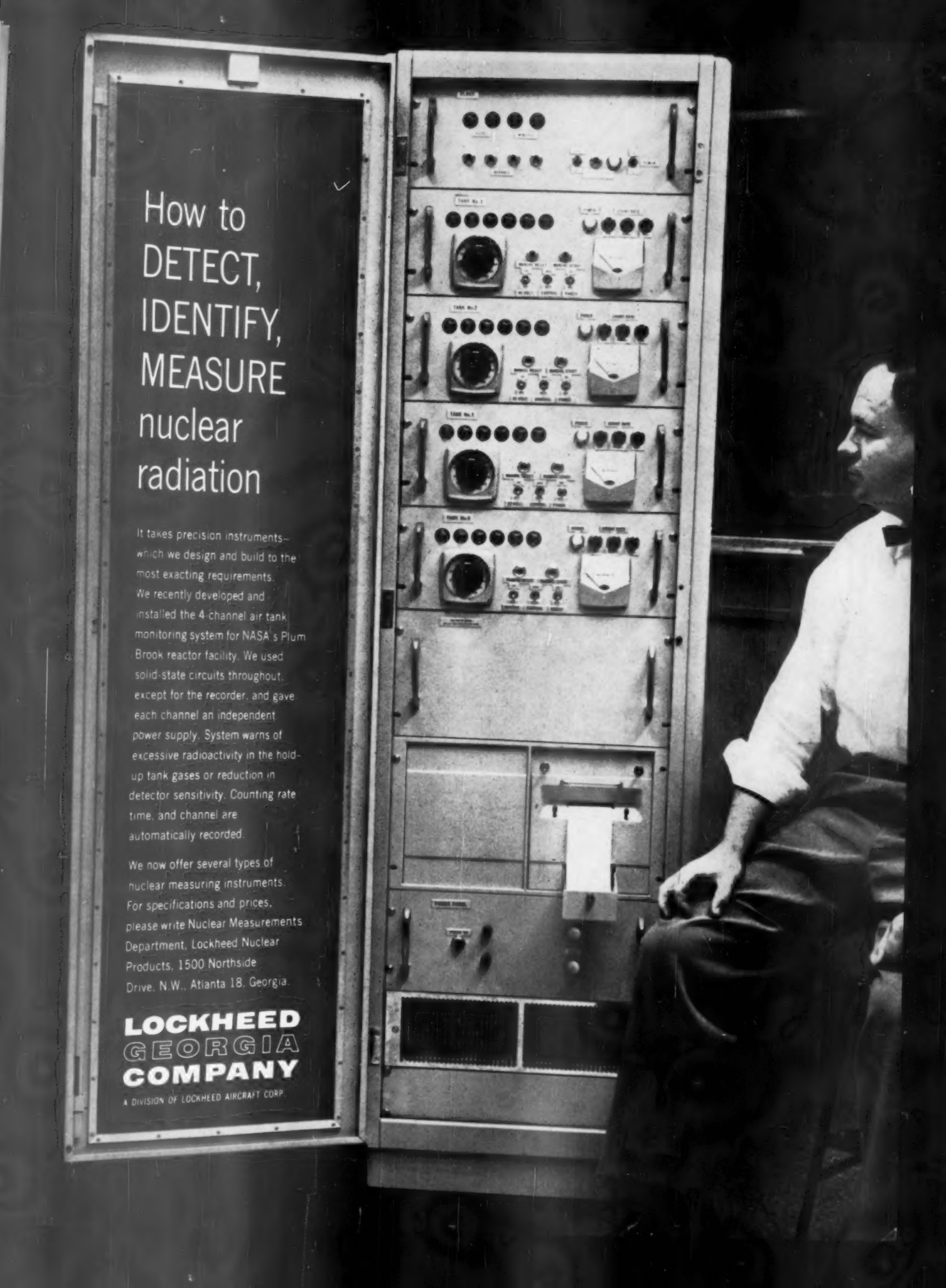
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